Los Alamos
NATIONAL LABORATORY

Los Alamos, New Mexico 87545

LA-13048-PR

Physics Division Progress Report 1994

LA-13048-PR
Progress Report

Physics Division Progress Report

January 1, 1994–December 31, 1994

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Front Cover:
A magneto-optic trap built by Los Alamos physicists confines cesium atoms as part of the atomic parity nonconservation experiment. The optical trap consists of six laser beams that intersect in a glass vacuum cell. The glowing (red) spot in the center is 10^8 cesium atoms cooled to mK temperatures by the laser beams and suspended by laser-light pressure.

Art direction and cover design by Pete Sandford, Group CIC-1.
Publications (Appendix B) compiled by M. Elizabeth Allred.
Cover photo by John Flower, Group CIC-9.

The four most recently published reports in this series, unclassified, are LA-12140-PR, LA-12336-PR, LA-12501-PR, and LA-12804-PR.

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Progress Report

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Physics Division Progress Report

January 1, 1994–December 31, 1994

Compiled and Edited by
Grace Y. Hollen
Gottfried T. Schappert

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PHYSICS DIVISION PROGRESS REPORT

January 1, 1994–December 31, 1994

ABSTRACT

This issue of the Physics Division Progress Report presents accounts of significant progress in research and development achieved by Physics Division personnel. The report includes the Division mission statement and organizational structure, an article on the Division's industrial partnership initiatives, selective research highlights articles, project descriptions, the Division staff and funding levels for FY94, and a listing of publications and presentations. The report represents the five main areas of experimental research and development in which the Physics Division serves the needs of Los Alamos National Laboratory and the nation in defense and in the applied and basic sciences: (1) biophysics, (2) hydrodynamic and x-ray physics, (3) neutron science and technology, (4) plasma physics, and (5) subatomic physics.

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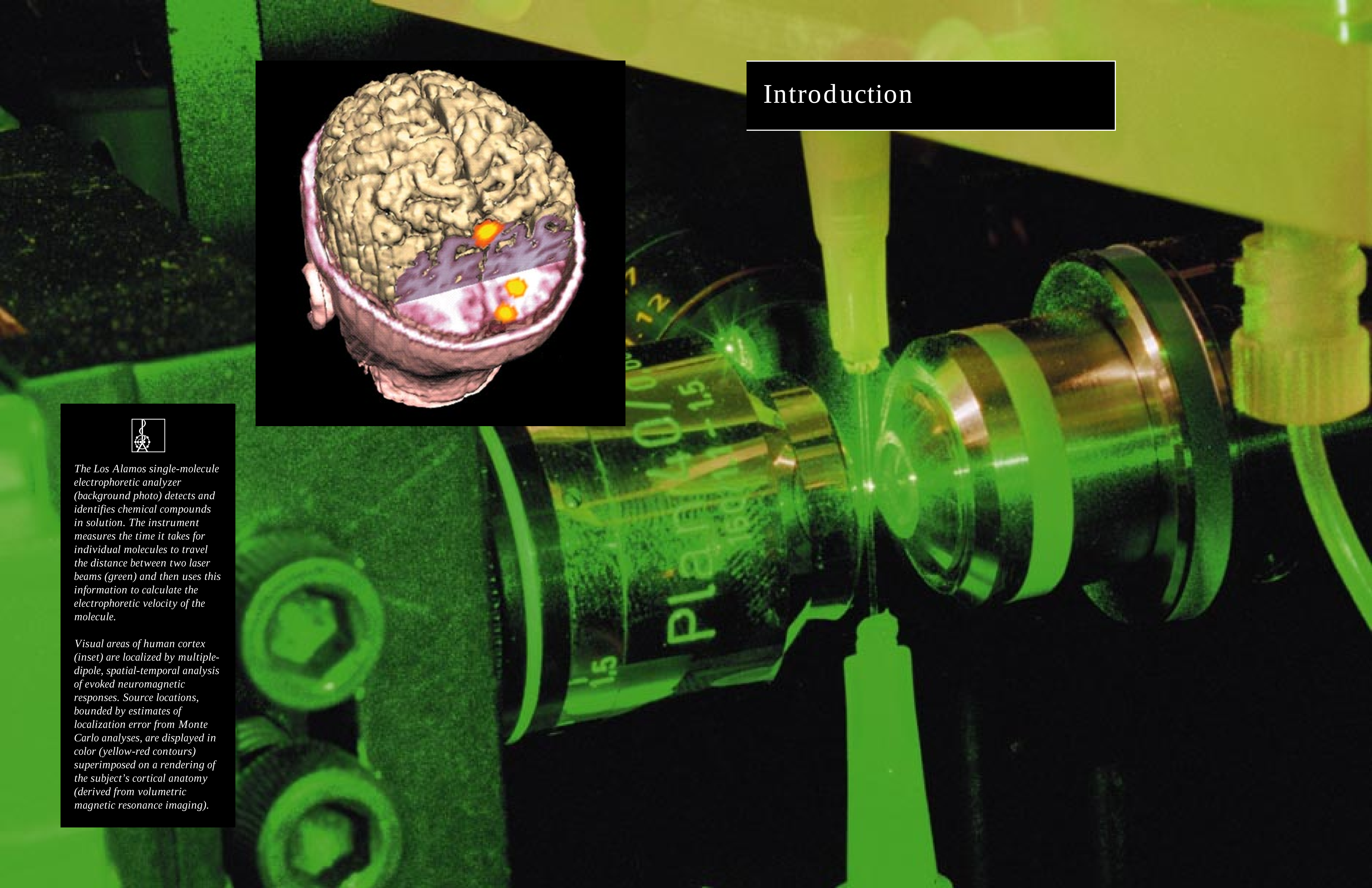


Introduction

The Los Alamos single-molecule electrophoretic analyzer (background photo) detects and identifies chemical compounds in solution. The instrument measures the time it takes for individual molecules to travel the distance between two laser beams (green) and then uses this information to calculate the electrophoretic velocity of the molecule.

Visual areas of human cortex (inset) are localized by multiple-dipole, spatial-temporal analysis of evoked neuromagnetic responses. Source locations, bounded by estimates of localization error from Monte Carlo analyses, are displayed in color (yellow-red contours) superimposed on a rendering of the subject's cortical anatomy (derived from volumetric magnetic resonance imaging).

Mission and Goals

The mission of the Physics Division is to further our understanding of the physical world, to generate new technology in experimental physics, and to establish a physics foundation for current and future Los Alamos programs.

The goals of the Physics Division are to

• provide the fundamental physics understanding supporting Laboratory programs;

• investigate the basic properties of nuclear interactions, high energy-density systems, and biological systems with a view toward identifying technologies applicable to new Laboratory directions;

• identify and pursue new areas of physics research, especially those to which the unique capabilities of the Laboratory may be applied;

• explore interdisciplinary areas of scientific endeavor to which physical principles and the methods of experimental physics can make an important contribution; and

• maintain strength in those disciplines that support the Laboratory mission.

The Physics Division pursues its goals by

• establishing and maintaining a scientific environment that promotes creativity, innovation, and technical excellence;

• undertaking research at the forefront of physics with emphasis on long-term goals, high risks, and multidisciplinary approaches;

• fostering dialogue within the Division and the scientific community to realize the synergistic benefits of our diverse research interests;

• encouraging the professional development of each member within the Division; and

• conducting all of its activities in a manner that maintains a safe and healthful workplace and protects the public and the natural environment.

The organization of the Physics Division is illustrated in Fig. I-1. Figure I-2 shows Physics Division activities by group. Details of the Division's staff and funding levels for fiscal year 1994 are presented in Appendix A. Publications, presentations, and patents are listed in Appendix B.

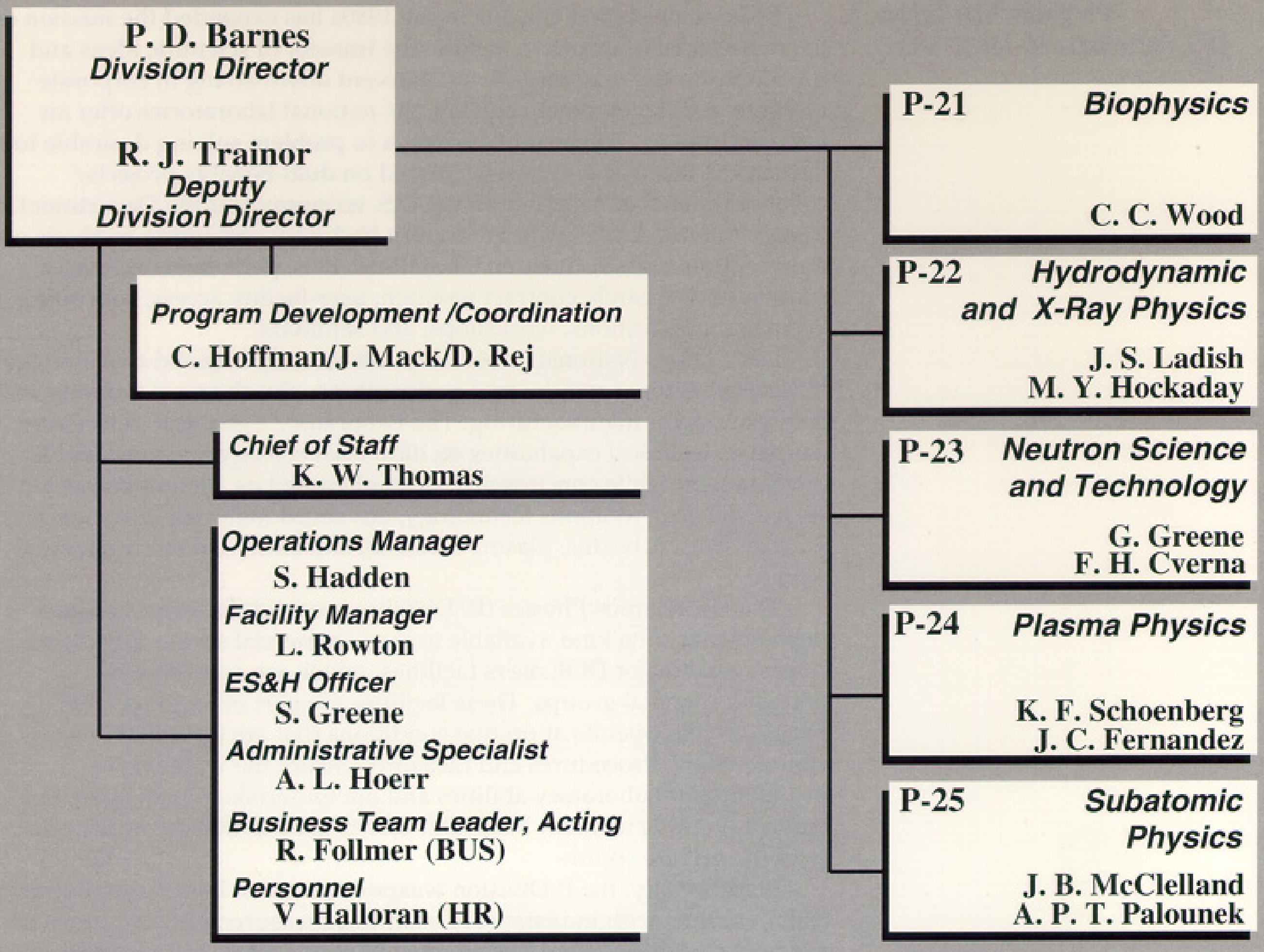


Fig. I-1. Physics Division Organizational Chart.

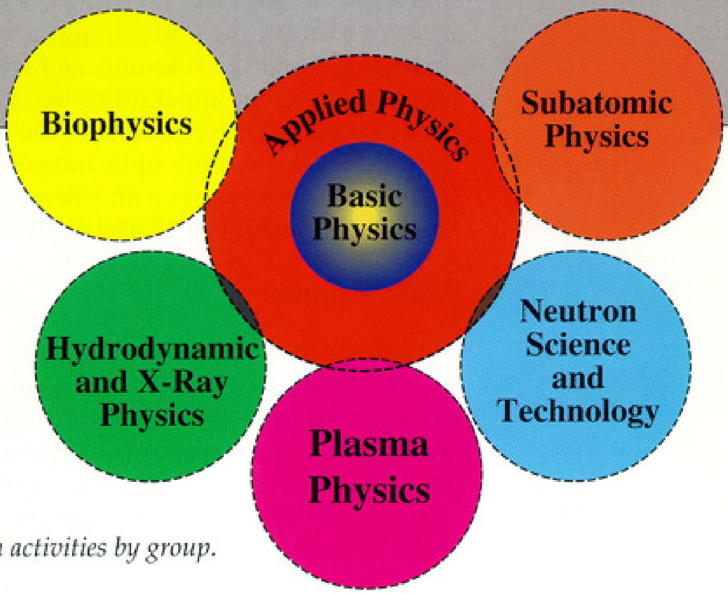


Fig. I-2. Physics Division activities by group.

Industrial Partnerships in Physics Division

D. J. Rej [(505) 665-1883] (DDP)

Introduction

Federal legislation enacted in the 1980s has expanded the mission of the national laboratories to include the transfer of scientific ideas and inventions to the marketplace. With recent down-sizing in corporate research and development centers, the national laboratories offer an interdisciplinary, concurrent approach to problem solving desirable to industry. Particular emphasis is placed on dual-benefits projects/collaborations that benefit both the U.S. economy and the Department of Energy (DOE). A variety of laboratory/industry partnering methods are now routine. Options include laboratory visits, personnel exchanges, cooperative research, contract research, user-facility access, consulting, licensing, publications, workshops, and seminars.

Los Alamos National Laboratory has recently targeted two strategic industrial sectors for industrial partnerships: the chemical industry and heavy and light manufacturing. The Laboratory's goal is to effectively couple its technical capabilities on industrial ecology and sustainable development while concurrently strengthening Los Alamos competencies such as nuclear-weapons technology, advanced materials, bioscience, nuclear science, beams, plasma research, and earth and environmental science.

The Los Alamos Physics (P) Division is one of the largest physics departments of its kind available to the commercial sector. P Division runs several major DOE users facilities, which are accessible by nongovernmental groups. These facilities are part of ongoing DOE programs and operate at unique conditions that are unavailable commercially. Procedures and measures ensure the widespread availability of Laboratory abilities and are undertaken in an open, fair, and competitive manner. Particular care is used to avoid competition with the private sector.

Traditionally, the P-Division weapons program has demanded strong collaborations with industry. For example, measurements of ultrashort, nonlinear, highly dynamic phenomena in the nuclear test program have required a new generation of high-speed electronics transmission and recording devices. For more than 20 years, our staff has worked side by side with their industrial counterparts both at Los Alamos and at industrial sites (*e.g.*, Tektronix and Hewlett Packard) to design and develop prototype apparatuses that have been subsequently commercialized. Several state-of-the-art products (*e.g.*, subnanosecond recording devices, fiber-optic transceivers, subpicosecond time analyzers) have become standards with widespread use by microelectronics manufacturers for testing and analyses.

User Facilities

Weapons Neutron Research Facility

A prime example of a P-Division user facility is the Weapons Neutron Research (WNR) Facility (Fig. 1), a unique facility capable of producing a broad spectrum of high-energy neutrons generated through spallation by the 3-μA, 1,000-MeV proton beam at the Los Alamos Meson Physics Facility (LAMPF) accelerator. A number of private companies, including Amdahl, Boeing, Honeywell, LSI Logic, and Texas Instruments, have purchased WNR beam time to test the resistance of a variety of electronics components against single-event upsets and latchups caused by cosmic rays. The WNR beam is unique in that it closely resembles the spectrum of neutrons generated by cosmic radiation, but it is much more intense, for example, 5 orders of magnitude over background at aircraft altitudes (Fig. 2).

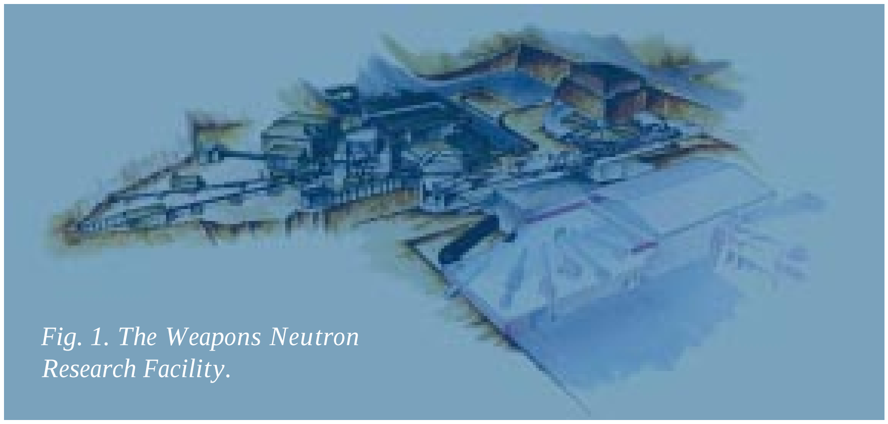
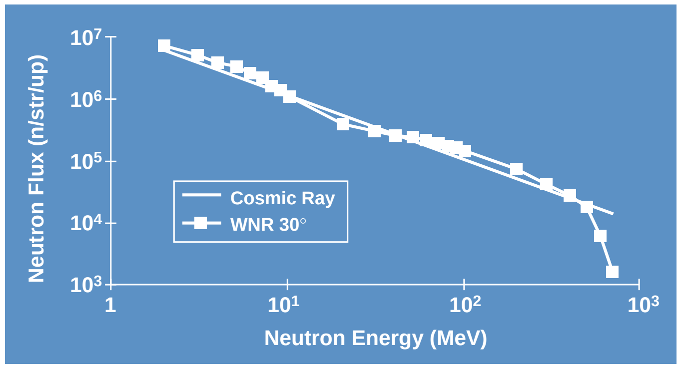


Fig. 1. The Weapons Neutron Research Facility.

In another program, P Division and IBM staff are using the WNR proton beam to make high-temperature superconductors (HTSCs) practical. Most HTSCs have limited utility because of the presence of movable current vortices that cause electrical resistance at relatively low temperatures (30 K). When bombarded by the WNR proton beam, the constituent bismuth atoms in the HTSC materials undergo fission up to 10^{14}/cm^3-h. The resulting radiation damage immobilizes the current vortices and thereby increases the critical current density by 3 orders of magnitude in bismuth-based HTSCs (Fig. 3).

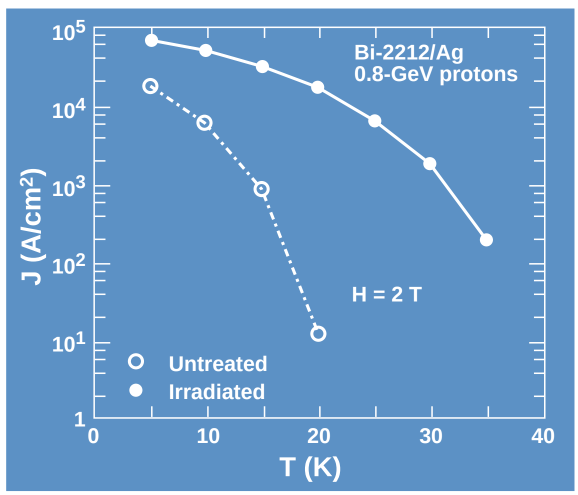
Fig. 2. Neutron flux at the WNR Facility and the atmospheric cosmic-ray-induced neutron flux at aircraft altitudes. The cosmic-ray flux is multiplied by approximately 10^5.



Plasma Processing Research Facility

Another popular P-Division user facility is the Plasma Processing Research Facility (PPRF), which houses a collection of unique, interrelated technologies and devices originally developed for the DOE magnetic and inertial confinement fusion energy programs. PPRF is situated in unclassified areas with over 40,000 ft^2 of laboratory space, and the facility is operated in collaboration with the Los Alamos Materials Science and Technology, Nuclear Materials Technology, Chemical Science and Technology, Theoretical, Technology and Safety Assessment, Applied Theoretical Physics, and Engineering Sciences and Applications Divisions. The primary activity of the PPRF is the development of plasma science and base technologies for a variety of applications, including the synthesis of advanced materials; advanced, environmentally conscious manufacturing; pollution prevention; and cleaning and decontamination.

Fig. 3. Persistent current density measured in Bi-2212 before and after irradiation to 10.5 x 10^{13} fission fragments/cm^3.



The plasma source ion implantation (PSII) experiment, used primarily for metallurgical applications, is the world's largest ion implanter and is capable of handling large, heavy workpieces in a 15-ft-long, 5-ft-diam plasma reactor. The PSII effort includes the largest CRADA (cooperative research and development agreement) at Los Alamos: a four-year, $14 million joint venture with General Motors Corporation initiated in 1992. Other activities include other CRADAs, technical consulting agreements, and work for other research and development with Alcoa, Litton Electron Devices, Empire Chrome, Kodak, Black and Decker, Videojet Systems, Jasco Tools, Burkhardt America, and A.O. Smith.

The coaxial thruster experiment (CTX) is an outgrowth of DOE energy and NASA space propulsion programs. CTX consists of a 3-ft-diam coaxial plasma gun used to investigate a variety of materials-surface-treatment manufacturing methods. A CRADA with 3M Corporation is in place to apply this technology for the treatment of polymers.

In the Anaconda high-intensity pulsed-ion-beam deposition experiment, Los Alamos is collaborating with several manufacturers to

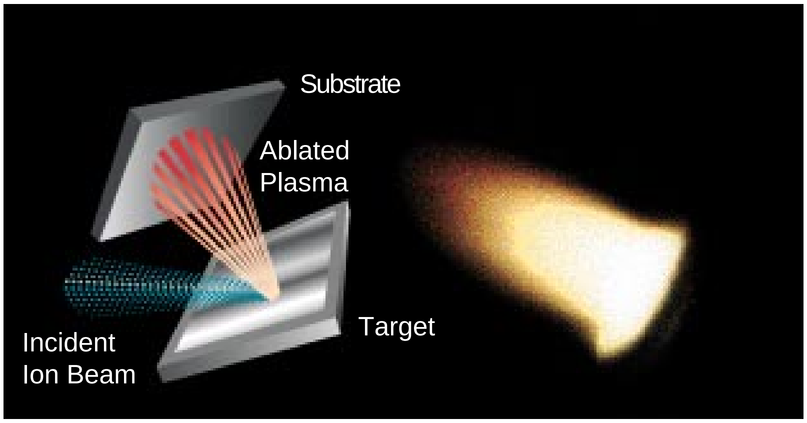


Fig. 4. Schematic diagram of the high-intensity pulsed ion beam deposition process and photograph of plume from a 75-mm-diam high-temperature superconductor target after irradiation by the intense ion beam. A high-energy beam is propagated onto a solid target and subsequently evaporates and ionizes a substantial amount of the target surface. The evaporated material (shown in red) is then deposited at record rates onto an adjacent substrate as a polycrystalline or amorphous film.

produce novel coatings at unprecedented rates. This particular experiment makes use of the Laboratory's 400-keV, 35-kA, 400-ns intense-light ion-beam. As illustrated in Fig. 4, the beam is propagated into a solid target, which results in the evaporation and ionization of substantial amounts of target material. The ablated plasma may then be condensed at phenomenal rates onto an adjacent substrate. In collaboration with S.I. Diamond Corporation of Houston, P-Division staff used this beam on a graphite target to deposit diamond-like carbon films. These films exhibited promise as field emitters used in cold cathodes for future flat-panel displays.

Plasma reactors are being used for the plasma etching and decontamination experiment to etch surface layers of materials from a variety of engineered objects. Although present research is in direct support of DOE decontamination of radioactive actinides, many civilian-sector surface cleaning applications have been identified.

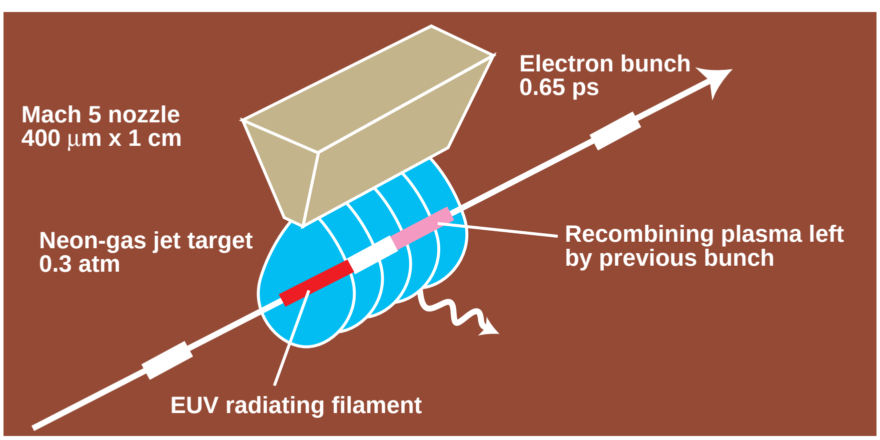
High-density, uniform, contamination-free, inductively coupled radio-frequency plasma sources are being developed with the semiconductor industry. In 1994, a CRADA with Novellus Systems, Inc., was executed to characterize and optimize a deposition / etch tool scheduled to be introduced into the semiconductor manufacturing market in 1995. P-Division staff are also leaders in the diagnosis and control of deleterious particulates, which dramatically reduce wafer yield if they form in plasma tools.

Additional Examples of Industrial Partnerships

Electronics

Los Alamos has a CRADA with Northrop-Grumman Corporation to produce a debris-free extreme-ultraviolet (EUV) source for photolithography in semiconductor fabrication. The source uses plasmas generated by a compact high-energy electron beam injected into a plasma (Fig. 5). Anomalous deposition into the plasma is observed through a resonant beam-plasma interaction (Fig. 6). Quality control sensors are also being developed for semiconductor manufacturers. A unique gas proportional counter, originally developed for the Sudbury Neutrino Observatory, is being commercialized to monitor ultralow background emission of naturally occurring radioactivity.

Fig. 5. Debris-free plasma radiation source for extreme-ultraviolet (EUV) lithography. EUV is generated by the anomalous interaction of a short electron bunch with a target plasma. The bunch length must equal the electron plasma wavelength.



This emission must be monitored to minimize deleterious single-event upsets that are becoming increasingly more important in next-generation microelectronics circuits.

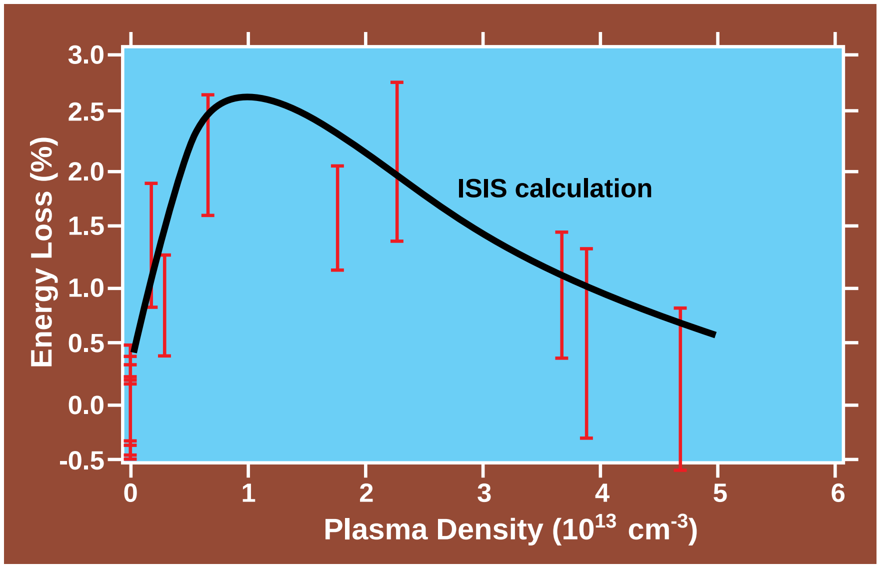


Fig. 6. Energy loss of a 15.5-MeV, 15-ps electron bunch in a 10-cm plasma cell. The data are observations, whereas the curve denotes a simulation with a 2.5 dimensional particle-in-cell simulation. The observed energy loss is up to 50,000 times that expected from classical electron collisions.

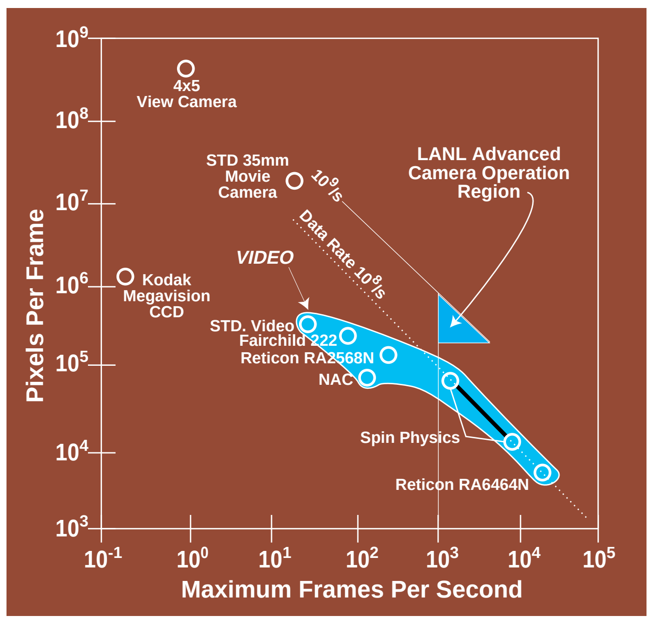
Environment

In 1994, Santa Fe Technologies, Inc., of Santa Fe, New Mexico, obtained an exclusive license from Los Alamos to commercialize lidar (**LI**ght **D**etection **A**nd **R**anging) software (copyrighted by P-Division staff) for transportation-related air-quality studies. In addition, a CRADA with Plasma Technologies, Inc., is under way to co-develop commercial plasma torches for the efficient and effective destruction of toxic chemicals.

Health Care

Los Alamos has a CRADA with Conductus, Inc., of Sunnyvale, California, to develop and commercialize superconducting image sensors to measure minute magnetic fields (about a billion times smaller than Earth's magnetic field) generated by the human brain and heart. In another effort, a fast, digital x-ray camera (Fig. 7), originally developed as a nuclear weapons diagnostic, has been modified for fast-fluoroscopy applications in collaboration with the Henry Ford Hospital Sports Medicine Clinic in Detroit, Michigan.

Fig. 7. X-ray camera performance phase space.



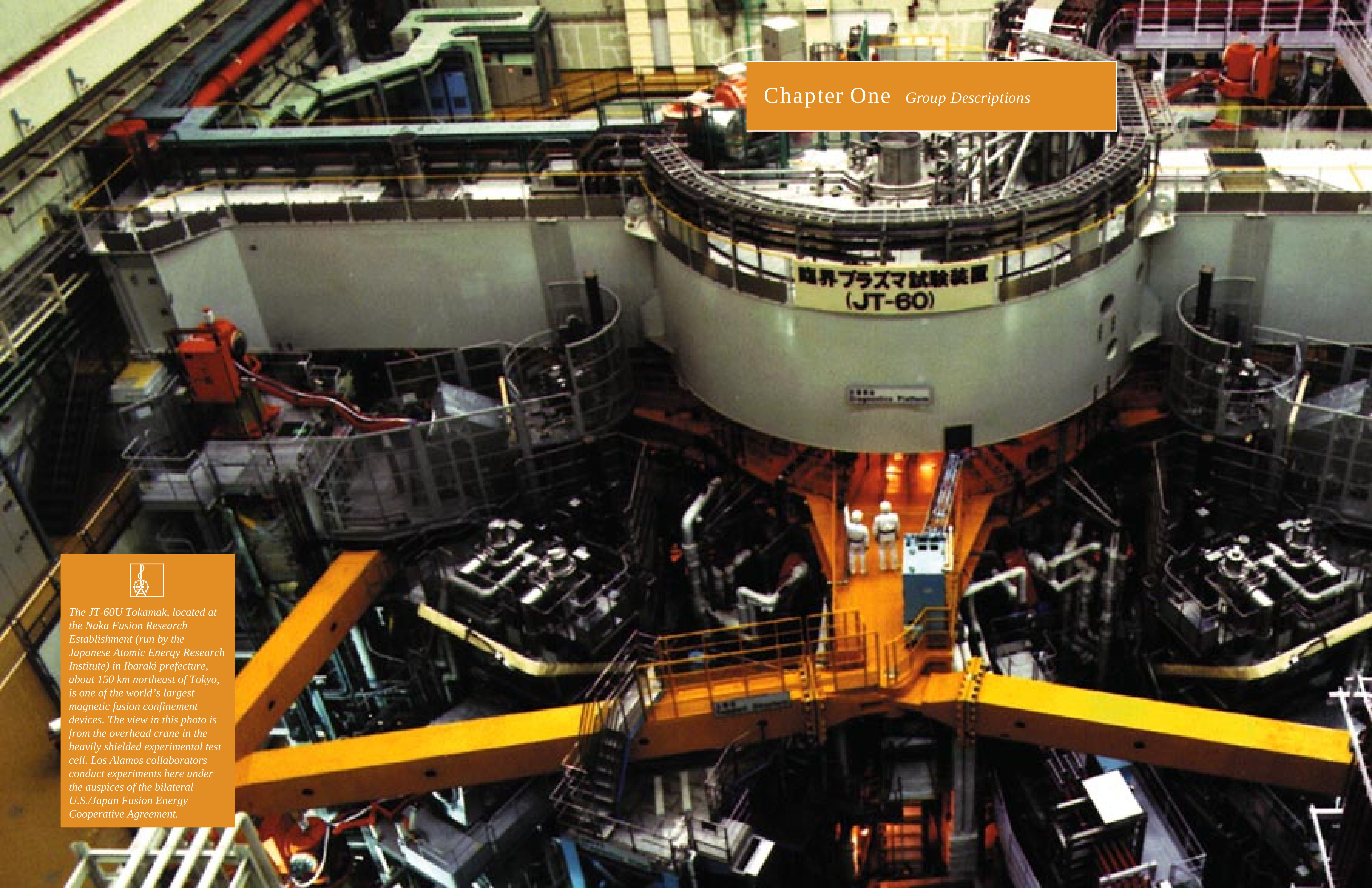
Transportation

A CRADA with NTN, Inc., of Ann Arbor, Michigan, is under way to co-develop an advanced fiber-optic, antilock-brake wheel rotation for automobiles and trucks. The sensor uses a novel Faraday rotation technique developed for the nuclear fusion and weapons programs.

Supplementary Information

Further information about P-Division capabilities is available by way of the Internet through the DOE Technical Information Network (http://www.dtin.doe.gov). This network is designed to encourage better partnerships with industry and the American business community at large. Eleven DOE Laboratories and Facilities are represented in this comprehensive data base. Information includes technical staff expertise, user facilities, technologies available for licensing, partnering mechanisms, and federal funding opportunities.

Chapter One *Group Descriptions*



The JT-60U Tokamak, located at the Naka Fusion Research Establishment (run by the Japanese Atomic Energy Research Institute) in Ibaraki prefecture, about 150 km northeast of Tokyo, is one of the world's largest magnetic fusion confinement devices. The view in this photo is from the overhead crane in the heavily shielded experimental test cell. Los Alamos collaborators conduct experiments here under the auspices of the bilateral U.S./Japan Fusion Energy Cooperative Agreement.

P-21: Biophysics

C. C. Wood, Group Leader

Introduction

The mission of Group P-21, Biophysics, is to apply physics knowledge and techniques to an increased understanding of important biological phenomena and, in turn, to use biological systems to elucidate physical principles of complex phenomena. Group members are engaged in biophysical research over a wide range of physical scales, including the characterization of the structure and dynamics of protein molecules and their implications for protein function; ultrasensitive detection and characterization of individual molecules using laser fluorescence; the molecular basis of signal transduction in retinal photoreceptors; techniques for prolongation of storage of human blood; design and implementation of biologically inspired robots and adaptive digital hardware; development, validation, and application of noninvasive techniques for measurement of human brain function; and development of three-dimensional computational models of the human brain.

The Biophysics Group (P-21) was founded in 1988 with the goal of exploiting the scientific and technical resources of the Physics Division in the biosciences. The group has strengthened existing biological projects within the Division and initiated new bioscience efforts in a number of directions.

Single-Molecule Detection

Members of P-21 and their collaborators have extended their recent accomplishment of a long-sought goal of researchers in ultrasensitive detection—the detection and characterization of single molecules in a liquid. The goal of this research is to measure and characterize the spectroscopic properties of individual molecules (Fig. 1). Such spectroscopic measurements can be used to identify the presence of a particular molecular species in an extremely dilute solution, or they can be used to probe the local environment that surrounds an individual molecule. The former capability promises a new level of speed and sensitivity for medical diagnostics, whereas the latter capability makes it possible to study properties of biological systems that cannot be measured when lack of sensitivity confines measurements to the determination of the average properties of a large ensemble of microenvironments. Thus far, the spectroscopic properties measured at the single-molecule level include emission spectra, fluorescence lifetime, and total emission intensity. Recently the single-molecule spectroscopic approach has been extended to include single-molecule electrophoresis. We are exploring applications of the new technology both for basic research and for medical diagnostics.

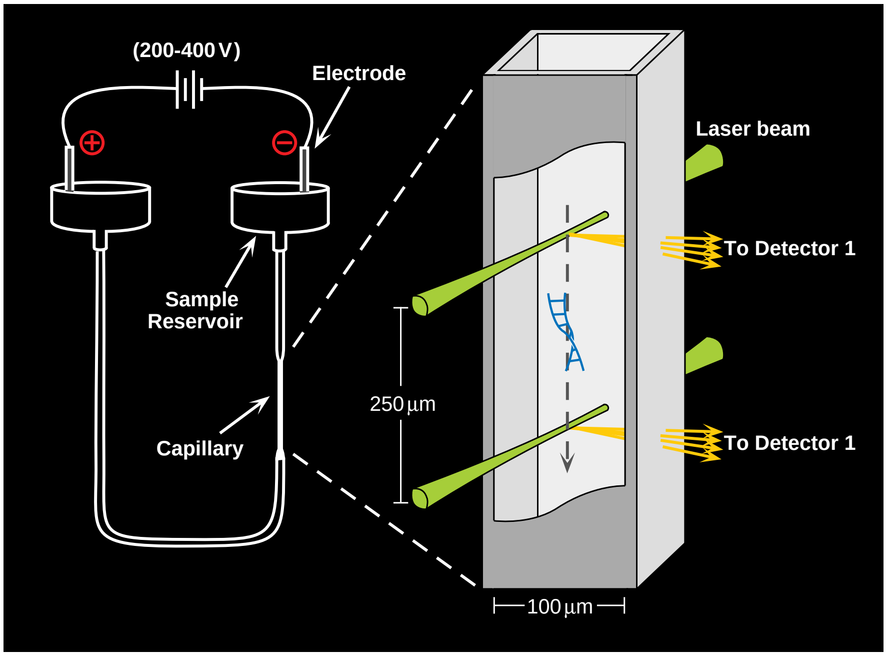


Fig. 1. The Los Alamos single-molecule electrophoretic analyzer detects and identifies chemical compounds in solution. When a voltage is applied to the electrodes, the molecules (shown in blue) in the solution migrate toward the cathode or anode, depending on their charge. As the individual molecules in the solution pass through the two laser-illuminated spots, they emit bursts of fluorescence. The photons from each burst are then collected by the lens of a microscope and detected by a light-sensitive photodiode. The detection electronics reject scattered light by the use of a time-gated window set to detect only delayed fluorescent photons. The instrument measures the time it takes for each molecule to travel the distance between the two laser beams and then uses this information to calculate the electrophoretic velocity of the molecule. The computer then classifies every molecule detected according to its velocity and identifies the molecular species that are present in the solution.

Retinal Phototransduction

P-21 work on retinal phototransduction stems from the observation that the visual pigment rhodopsin, shared by man and all other vertebrates, is linked to the photoreceptor ion channels via a G-protein (transducin), which modulates the rod enzyme cyclic-GMP phosphodiesterase. G-proteins are guanine-nucleotide-binding proteins that link cellular-signal receptors to amplifying-effector systems and thus participate in the flow of information across the cell membrane. The G-proteins serve in many cell types as a locus for the function of an activated receptor that modulates nucleotide binding to the G-protein and thereby modulates its function. Many neuronal and hormonal signals are dependent upon the participation of G-nucleotide-binding proteins; they can amplify, modulate, and communicate signals. There is evidence that a single, activated rod photon receptor (rhodopsin) can in turn activate more than 30,000 G-proteins within a very short time period (*i.e.*, the molecular basis of single-photon sensitivity). P-21 is studying two aspects of G-protein-dependent, photon-based signal processing. The first relates to evidence for cooperation between the G-protein and the active photon receptor, rhodopsin. The binding of the first G-protein to rhodopsin facilitates the binding of the second by 2 orders of magnitude. This positive cooperativity appears to be essential for the highly sensitive, yet noise-resistant, operation of biological photon transducers. Group members are also studying the role of rod protein phosphorylation in regulating rod sensitivity, and especially signal amplification, in the dark adapted state.

Erythrocytes Research

P-21 studies of mammalian erythrocytes (red blood cells) are based on biophysical relationships between the ratio of red-cell-membrane area and cytosolic volume. This ratio and the intrinsic physical properties of red-cell membranes reliably predict whether or not erythrocytes can traverse small capillary channels. Refrigeration degrades red-cell-membrane area principally by peroxidative pathways that culminate in the extrusion of vesiculated lipid. Refrigeration also attacks the sodium transport apparatus via peroxidative pathways and, to a lesser extent, via biochemical modifications of the gain control on the sodium pump. The biochemical and biophysical basis of refrigeration-induced damage has been characterized, and effective countermeasures have been identified. Current work focuses on the optimization of protective measures and empirical testing of their efficacy by measuring erythrocyte survival in the transfusion recipient. The hypothesized analogy between red-cell senescence in vivo and refrigeration-induced damage is also an area of study. Finally, dramatic individual differences in red-cell biophysical properties and Na^+ pump activities have been observed among genetically diverse populations of humans. The potential clinical significance of these differences is being investigated.

Protein Dynamics Studies

The goals of P-21 studies of protein dynamics are to describe protein motion in atomic detail and to understand the consequences of protein dynamics for protein function. Our approach is to bring crystals of the CO-complex of the protein myoglobin down to liquid-helium temperatures in a cryostat, photolyze the CO with a flash of light, and observe the subsequent rebinding reaction with x-ray Laue crystallography. We have constructed and tested a low-temperature Laue camera, determined the freezing conditions for the CO crystal that maintain the high degree of order required for Laue diffraction, and analyzed diffraction patterns obtained at 5 K. Our results show that under the right conditions protein crystals can be frozen and still produce high-resolution (better than 1.9 Å) Laue diffraction data. This approach is being extended to the investigation of the photosynthetic reaction center.

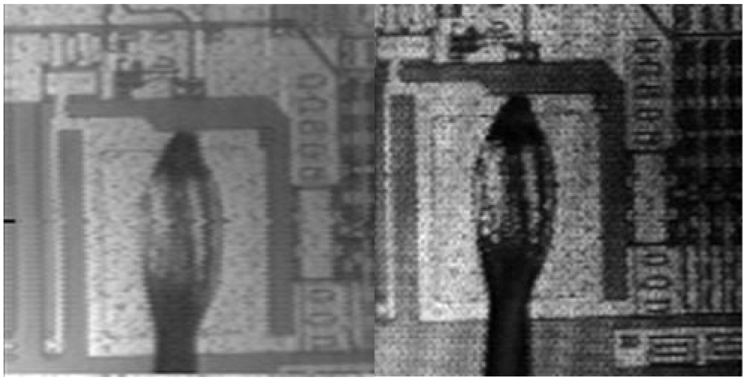
Noninvasive Imaging Techniques

The P-21 neuroscience effort focuses on the use of magneto-encephalography (MEG) and magnetic resonance images (MRI) to develop improved techniques for noninvasive imaging of the human brain. MEG involves the use of **S**uperconducting **QU**antum **I**nterference **D**evices (SQUIDs) to measure magnetic fields associated with human-brain activity. The magnetic fields of the brain (which are approximately a billion times smaller than that of Earth) require sensitive magnetic sensors, magnetic shielding from the environment (currently implemented as a shielded room), and advanced signal-enhancement and modeling techniques. Because magnetic fields readily penetrate the skull, MEG offers the potential for noninvasive measurement of brain function in much the same way that computed tomography and MRI allow the noninvasive measurement of brain *structure.* MEG has therefore generated considerable promise as a tool in basic neuroscience for functional mapping of the human brain, as a clinical tool for the assessment of neurological and psychiatric disorders, and as a possible signal for use in the development of neural prosthetics and human-machine interfaces and in other applied contexts. Group members are engaged in projects to design improved multichannel magnetic sensors, to develop more accurate mathematical models for localizing the electrical and magnetic signals from the brain, to validate MEG using known current sources in computational and physical models of the brain, and to use MEG to address important questions in basic neuroscience and in research on neurological and psychiatric disorders. An example of the use of MEG data and associated current estimation techniques to investigate the organization of the visual cortex in humans is presented by C. J. Aine *et al.* (C. J. Aine, J. S. George, D. Ranken, W. Tiee, E. R. Flynn, C. C. Wood, E. Best, S. Supek, J. Lewine, and J. Sanders, “Unexpected Features of Retinotopic Organization in Human Visual Cortex Revealed by Neuromagnetic Mapping,” in *Chapter II: Research Highlights*, Physics Division Progress Report, January 1, 1994–December 31, 1994, p. 36). Many of P-21’s neuroscience projects are conducted in collaboration with the VA / LANL / UNM Center for MEG, a consortium that includes Los Alamos, the University of New Mexico, and the Albuquerque Veterans Administration Medical Center, and is sponsored by the U.S. Department of Veterans Affairs.

Combining MEG and anatomical MRI with other functional imaging techniques such as functional MRI (fMRI) and positron emission tomography (PET) offers the opportunity to increase the combined spatial and temporal resolution of functional imaging techniques well beyond those of any single method. P-21 is engaged in developing mathematical models for combing these alternative forms of brain imaging. This work is part of a nationwide effort to develop three-dimensional computational models of the brain in which a variety of structural and functional information can be represented for storage, retrieval, and analysis.

Optical measurement techniques hold considerable promise for minimally invasive medical diagnostic imaging applications. The Physics Division is actively involved in the development of two optical technologies that will enable new diagnostics. Time-resolved optical tomography employs pulsed illumination and high-speed gated detection to characterize the time of flight of photons through highly scattering media such as biological tissue. With appropriate reconstruction techniques, this method allows characterization of three-dimensional optical properties from surface measurements. Such methods should prove very useful for characterizing head trauma (*e.g.*, spotting hemorrhage under the skull) or for monitoring cerebral circulatory accidents such as stroke.

For other applications, direct visualization via microscopic or endoscopic procedures provides the microanatomical detail required for diagnosis. Confocal techniques offer substantial enhancement of image contrast and three-dimensional spatial resolution in optical microscopy, but the large, complex optical and mechanical systems and the design limitations in flexibility and sensitivity have impeded many potential applications. P-21 has developed a novel approach using an electronically scanned illumination source with a common charge-coupled device camera to achieve true (computed) confocal imaging and to allow spectral imaging and dark-field / bright-field and other contrast mechanisms without requiring specialized optics (Fig. 2). Advanced imaging strategies can be employed for telemicroscopy or endoscopy to allow in-place, nondestructive imaging in relatively inaccessible locations. Endoscopic procedures for medical diagnosis and therapeutic intervention have become increasingly common, driven by requirements to minimize costs. The technology also has several potential defense applications, including imaging of inertial confinement fusion targets and inspection of devices for systematic and nondestructive stockpile surveillance.



Conventional Image *Confocal Image*

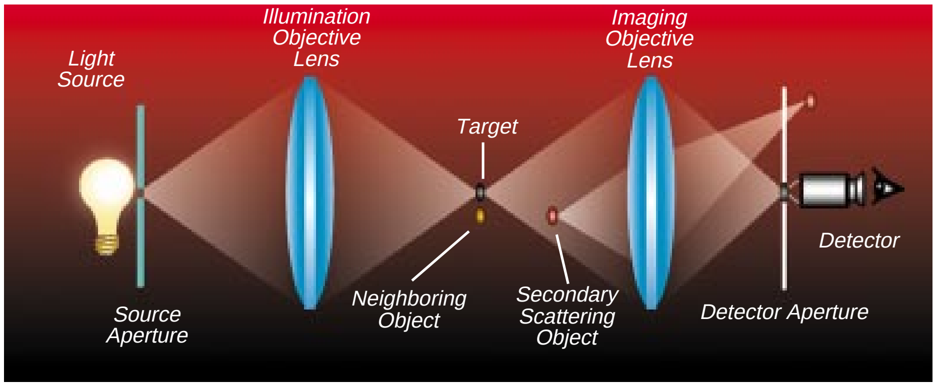


Fig. 2. In conventional confocal microscopy, light is focused onto a target and imaged onto a detector through a pinhole aperture. Neighboring objects in the focal plane are not illuminated, while the light from others is rejected by the aperture. In the digital system, the light source is electronically scanned, and a synthetic aperture is applied to data from a solid-state video camera.

Robotics

Recently, P-21 has begun investigations into the design, implementation, and application of biologically inspired robotics with simple, highly robust control circuits. This work promises to contribute both to an improved understanding of robotic control and to a variety of applications in which reliable, inexpensive robotic capabilities are required.

P-22: Hydrodynamic and X-ray Physics

Joe Ladish, Group Leader
Mary Hockaday, Deputy Group Leader

Introduction

The mission of Group P-22, Hydrodynamics and X-ray Physics, is to solve challenging experimental physics problems relevant to our national security, particularly when we can reduce the threat of war by helping ensure the reliability of our nuclear weapons stockpile and the limiting of the proliferation of weapons of mass destruction. We continue to maintain and enhance a creative, multidisciplinary team and state-of-the-art technology as a national asset. The group maintains a broad physics and engineering capability and pulse-power facilities to fulfill its mission. Physics disciplines include hydrodynamics, x-ray spectroscopy and imaging, plasma physics, radiation hydrodynamics, optics and fiber optics, microwaves, electromagnetics, atmospheric physics, and atomic physics. Engineering disciplines include analog and digital electronics; electro-optics, instrument design and fabrication; high-voltage, low-inductance, pulse-power engineering; and fast-transient data recording. P-22 is the home of the Pegasus II Pulse Power Facility and of the future Atlas High Energy Density Physics Center.

Nuclear Weapons Program Research

The mainstay of P-22 has been its support of the nuclear weapons program. P-22 applies the scientific and engineering expertise it has historically developed for the nuclear test program to investigate and understand crucial primary and secondary weapons-physics issues in a world without nuclear testing. The foundation of the present Los Alamos nuclear weapons program is Scientific-Based Stockpile Stewardship (SBSS), which requires the development of complex experiments on diverse facilities to address the relevant physics issues of the enduring stockpile.

In the portion of the nuclear weapons program involving high explosively driven aboveground experiments (AGEX I), we are studying the physics of a high-pressure shock wave and the material emitted or spalled as it unloads from a metal into a vacuum or a gas. Measurements of interest are the temperature history of the surface and the quantity and dynamics of the material emitted. These shock-wave studies are being done with conventional high explosives, as well as being investigated with Pegasus II as the driver. Additionally, P-22 is supporting the development of the Laboratory’s premier SBSS Facility, the Dual-Axis Radiographic Hydrotest (DARHT) Facility, by studying the beam physics of DARHT’s technical precursor, the Integrated Test Stand. Critical issues relating to DARHT’s performance are being addressed and advanced beam diagnostics needed for DARHT are being developed.

As part of the AGEX II program, the 4.6-MJ Pegasus II Pulse Power Facility is used to drive experiments of interest to the weapons community. Pegasus II can be used as a radiation driver or as an hydrodynamic driver. Experiments are being performed to investigate nonsymmetric hydrodynamic flow and ejecta formation of shocked surfaces. In addition, pulse-power research on improved radiation drivers, fast vacuum switching, and power flow channels are being pursued as we look to the future requirements of Atlas and explosive pulsed-power systems. P-22 has provided pulse-power and diagnostic expertise to Procyon, the Laboratory’s high-explosive pulsed-power system. Procyon set a record this year by producing over 1 MJ of soft x-rays with a thin-foil implosion.

P-22 is also home of Atlas, the next-generation 36-MJ pulse power facility. Atlas achieved Key Decision 1 this year: construction funding will become available beginning in FY96. Atlas will provide advanced radiation and hydrodynamic capabilities for weapon-physics and basic research. Research and development activities have been centered on component development, prototype design and testing, and investigation into the understanding of how the physics of interest scales to higher energies.

P-22 is deeply involved in protecting and archiving the volatile test data it took during the over 30 years of underground nuclear testing. The goal is to bring the group's data to a stable and readily accessible state. These data will be used as benchmarks for testing all future calculational tools.

P-22's plasma-physics expertise and ability to do large-scale integrated experiments has provided group members with the opportunity to be involved in several collaborations with the premier All-Russian Institute of Experimental Physics at Arzamus-16 (VNIIEF). These collaborations are based on our mutual interests in high-explosive pulse power whereby the Russians have clearly demonstrated the scalability to larger systems that are unmatched in the United States to date. In 1994, we participated in experiments both in Russia and at Los Alamos; these experiments investigated the superconducting properties of $YBa_2Cu_3O_7$ in 600-T fields; the plasma properties of the Russian MAGO system (Figs. 1 and 2), which is a possible candidate for magnetized target fusion; and the capabilities of a novel x-ray generator.

Group members are applying their understanding of electromagnetic-pulse (EMP) phenomena to a variety of important physics issues. These issues range from an understanding of EMP generation from chemical and nuclear explosions to the use of EMP for the possible detection of underground structures and tunnels.

The group has two vacuum-ultraviolet beamlines and two x-ray beamlines at the National Synchrotron Light Source (NSLS) at Brookhaven National Laboratory (BNL). These beamlines, which cover the photon energy range from 30 eV to 20 keV, are used to calibrate detectors and to pursue atomic-physics research. Over 100 detectors were calibrated for use in

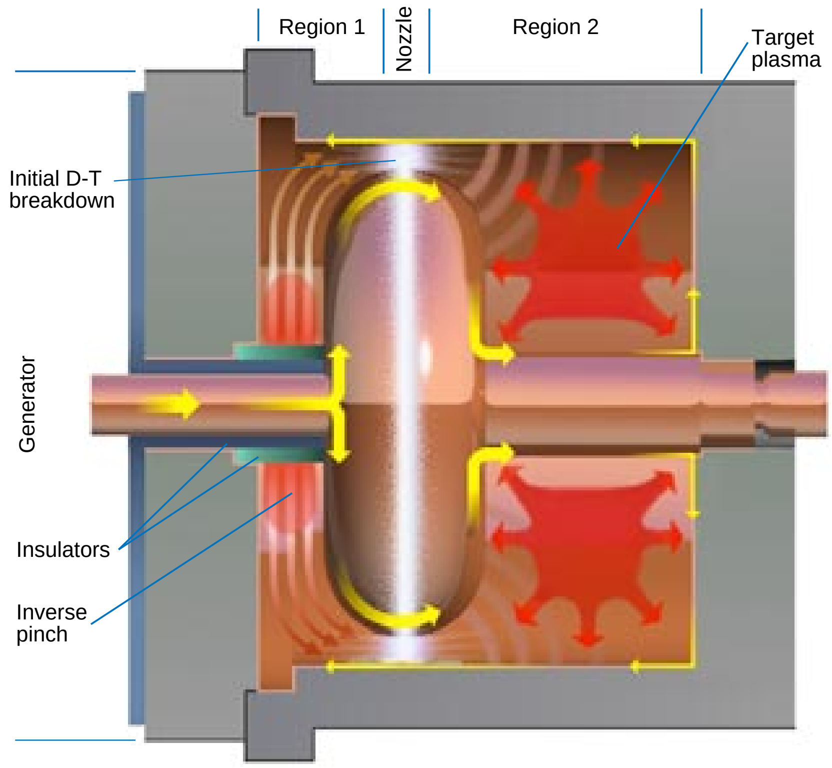


Fig. 1. The MAGO vacuum chamber. Current (Stage I in the graph below) flows in from the left along the axis and around the chamber walls, ionizing the low-pressure D-T gas near an insulator on the axis in the left-hand side of the chamber. The resulting plasma flows radially outward and around the copper knob just to the left of the center of the chamber during Stage II. During Stage III the plasma near the outer wall is imploded in the right-hand side of the chamber.

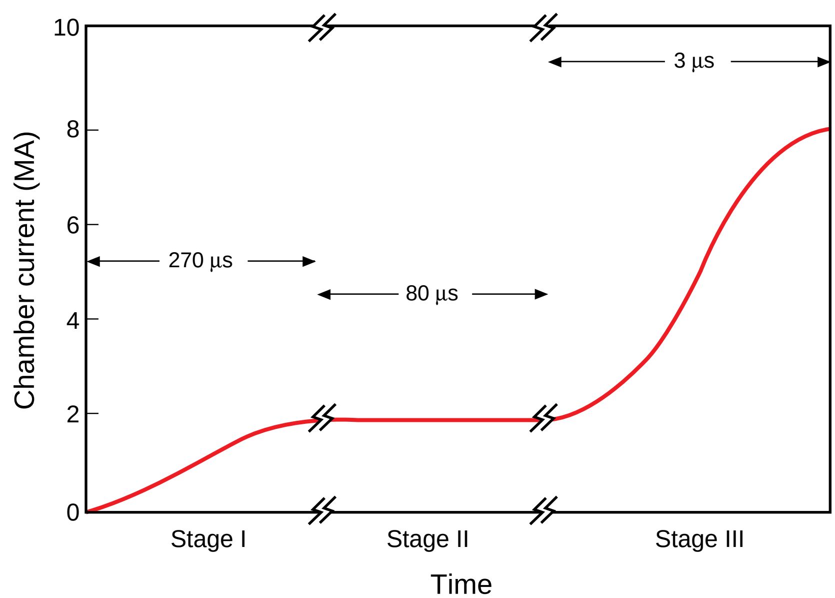


Fig. 2. Current in the MAGO vacuum chamber. In Stage I, a slowly rising current from a capacitor bank ionizes the plasma and drives it outward in an inverse z-pinch. After the plasma flows through the chamber nozzle (Stage II), an explosive-driven flux compression generator amplifies the current (Stage III), creating a voltage large enough to cause an electrical breakdown in the chamber and an implosion of the plasma.

AGEX II experiments this year. Group members are studying electron-electron interactions by measuring the multiple ionization of argon and neon near their respective K-edges. These measurements require the tunability and resolution of the synchrotron x-ray source. The one-electron model cannot predict multiple ionization of the atom because it ignores the electron-electron interaction. Understanding the magnitude of electron-electron interaction in simple systems helps to further delineate the limitations of the one-electron model.

Lidar

The group is interested in the programmatic usage of the elastic-backscattering lidar (**Li**ght **D**etection **A**nd **R**anging). P-22 is developing the capability to track effluent plumes from detonations such as hydrotests or other sources. The unique feature of the lidar is its ability to use the detected signal itself to point the lidar at a plume even after it has become subvisible. The elastic-backscattering lidar will be able to observe and detect the size and location of plumes at distances as great as 30 km or more. Volume wind-field measurements have been made with the elastic-backscattering lidar systems in collaboration with EES-5. A maximum-correlation technique has been used to analyze lidar data and to determine wind vectors within the region interrogated with the lidar. Wind-field information can be used to verify meteorological models and to help understand pollution problems for particular regions. Lidar experiments have been conducted to study the feasibility of using an elastic-backscattering lidar mounted on a miniature seeker technology integration satellite to track theater ballistic missiles from space.

Technology Transfer

Group P-22 has increased its involvement in technology transfer with several cooperative research and development agreements (CRADAs). Our knowledge of Faraday fiber-optic sensors is being applied to provide active feedback of the speed of the wheels of large trucks during braking. This work has recently been submitted for a patent. A debris-free, electron-beam-driven lithography source at 130 Å is being developed in conjunction with AOT Division and Northrup Grumman Corporation. This effort is an attempt to use the predicted anomalous energy loss of a short-pulse (less than a picosecond) electron beam in a preformed plasma to heat and further ionize the ions to a charge state such that efficient 130-Å emission will occur.

Challenging engineering problems must be solved for experiments to succeed. Such challenges include the remote control of instrumentation, specific instrument performance, and package design for both laboratory and field environments. P-22 has an in-house capability to design, prototype, and characterize new components and systems with specialization in microelectronics, high speed, and optoelectonics. In 1994, a new light-emitted-diode, fiber-analog data link was designed, fabricated, and delivered to the field. Ground-based discriminating electronics for single-photon imaging for the remote ultralow light imaging (RULLI) project were developed and tested; designs for airborne instrumentation are progressing. Industrial interactions include work with IBM and Motorola through CRADAs and funds-in agreements. A patent was issued for a 10-ps time interval meter (Fig. 3), and the Laboratory nominated the project for an IR 100 award.

The integration of our broad experimental physics and engineering expertise enables the group to fulfill its mission and opens the door to exciting future opportunities.

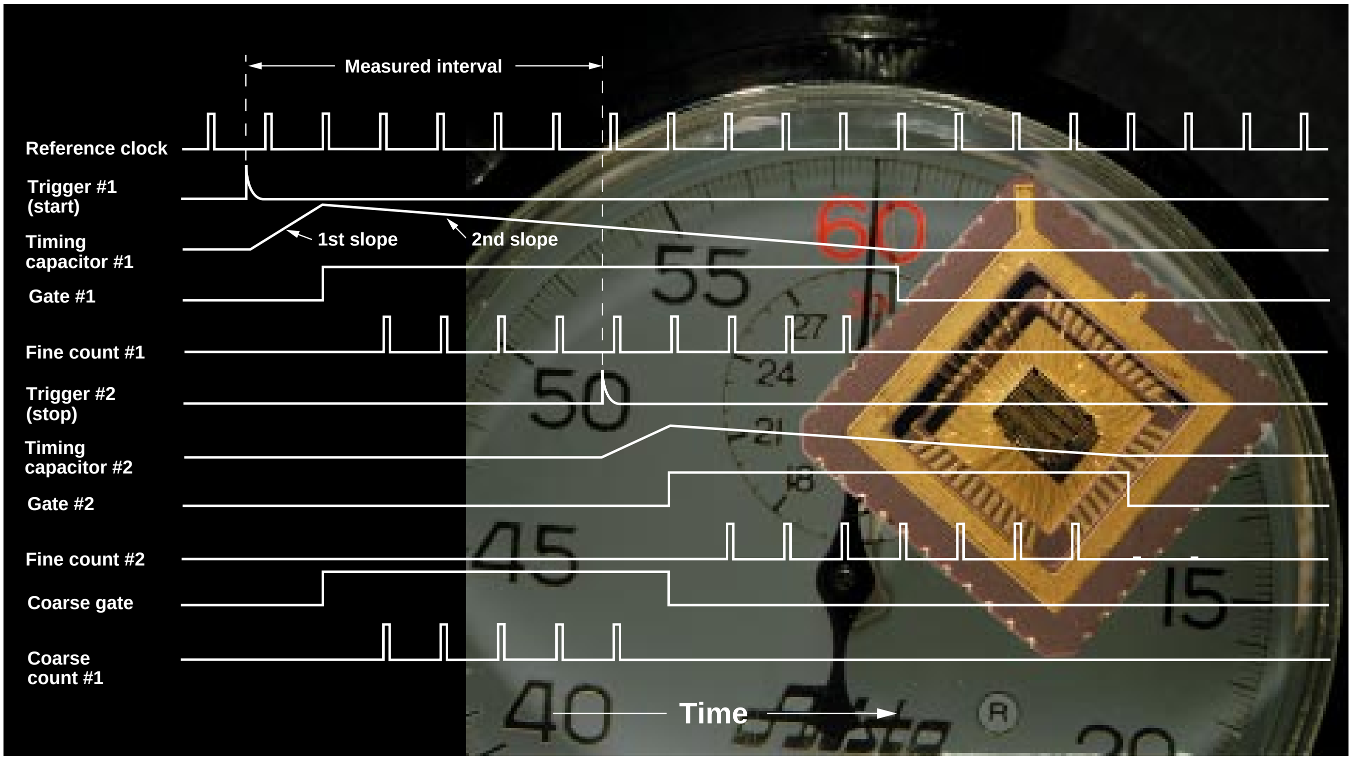


Fig. 3. A recently developed compact, inexpensive integrated circuit (IC) makes reliable time measurements with accuracies to 10 trillionths of a second. Multichannel modular time interval meters will be built using this IC and will substantially decrease the cost per measuring channel and improve performance.

P-23: Neutron Science and Technology

Geoffrey Greene, Group Leader
Frank Cverna, Deputy Group Leader

Introduction

The mission of Group P-23, Neutron Science and Technology, is threefold: (1) to conduct basic research on the interaction of neutrons with nuclei to advance nuclear physics and the Laboratory's capability in nuclear and non-nuclear hydrodynamic-device diagnostics; (2) to provide scientific and engineering support to Laboratory programs, including weapons stockpile stewardship and nonproliferation surveillance; and (3) to continue development of its capability in instrumentation, including the transfer of technology to military and commercial applications. P-23's major resources for experimental work include laboratories and computing networks located in Technical Area (TA) 3; the Weapons Neutron Research (WNR) Facility and beamlines at the (Manuel Lujan) Los Alamos Neutron Scattering Center (LANSCE), both of which are a part of the Los Alamos Meson Physics Facility (LAMPF); and the Ion Beam Facility (IBF), which has ceased experimental operations.

Basic Research

P-23's basic research involves a number of efforts. The Sudbury Neutrino Observatory (SNO), for example, an international effort involving institutions from Canada, the United Kingdom, and the U.S., will measure the flux and spectral shape of ≥5-MeV electron neutrinos produced in the fusion processes that power the Sun, and it will measure the total flux of all neutrino flavors above a threshold of 2.2 MeV. The SNO detector is situated 6,800 feet underground in a nickel mine near Sudbury, Ontario, to escape interactions from cosmic-ray particles. The central part of the detector is a 12-m-diam sphere that will be assembled from ultrapure acrylic panels. This acrylic vessel will house the 1,000 tonnes of heavy water that will be used as a neutrino target. The central volume of heavy water is shielded from natural radioactivity in the surrounding cavity by a secondary vessel containing 8,000 tonnes of regular (light) water. Members of P-23, together with SNO collaborators at the University of Washington, are presently engaged in a program to construct and deploy ^{3}He proportional counters into SNO to detect the neutrons liberated by neutral-current neutrino interactions in the heavy water. An interesting spin-off from this research involves the microelectronics industry. New-generation computer chips are thin enough that the decay of natural radioactive elements in the construction materials can create single bit flips from one binary number to another (Fig. 1). Consequently, members of P-23 will apply its knowledge gained with SNO research efforts to provide ultralow-background particle detectors for screening microelectronics components.

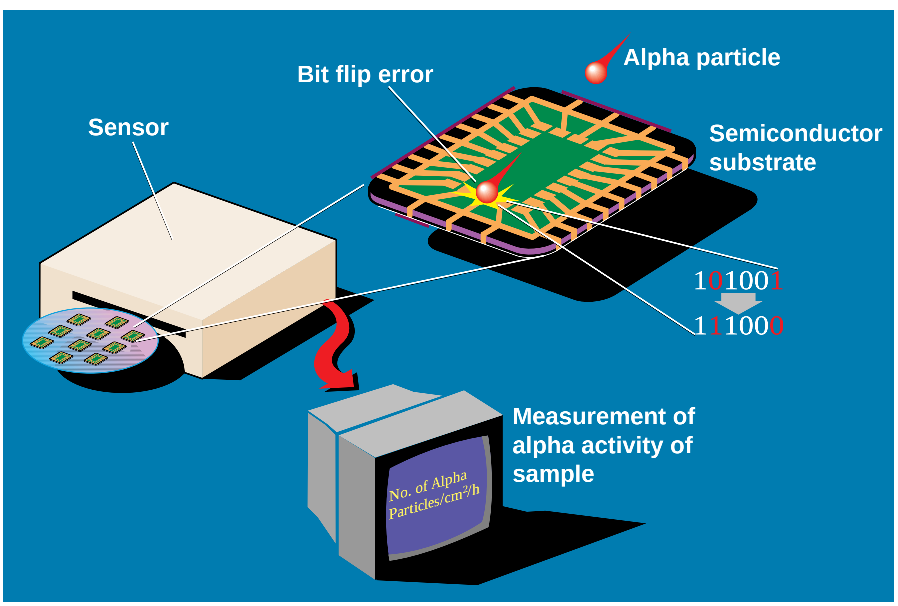


Fig. 1. As the semiconductor industry moves toward higher-performance integrated circuits with smaller feature sizes, computer chips become increasingly vulnerable to single-event upsets, "bit flips" caused by naturally occurring radiation emanating from the chip itself. Alpha particles passing through a semiconductor substrate can cause bit flips from one binary number to the other (shown in red).

Basic research at the WNR Facility includes experiments such as neutron-proton (n-p) bremsstrahlung, which is a fundamental two-nucleon process sensitive to meson-exchange currents and the off-shell character of the nucleon-nucleon interaction. P-23 has made substantial progress toward performing successful differential measurements of the n-p bremsstrahlung process by measuring neutrons and protons in coincidence from neutron interactions in a liquid hydrogen (LH_2) target at the WNR Facility. The goal of these measurements was to use the well-understood elastic-scattering reaction to demonstrate that n-p coincidences could be cleanly observed; the reaction was then used to characterize background and to develop analysis techniques for extracting n-p bremsstrahlung coincidence events.

High-energy gamma-ray production from fast-neutron-induced reactions on actinide samples is of interest for programmatic reasons and for basic nuclear physics. P-23 is using high-resolution germanium detectors at the WNR Facility to measure individual transitions in reaction product nuclei in an effort to observe individual reaction channels as a function of incident neutron energy. Detailed excitation function data have been obtained with the WNR white neutron source for reactions that are difficult to measure by other means. These data are useful for testing the validity of model calculations in the largely unexplored incident neutron energy region above 20 MeV and have numerous applications in science and technology.

The elementary n-p reaction plays a fundamental role in nuclear physics because it forms the basis for all neutron-nucleus interactions, as well as being of fundamental interest itself. Furthermore, this reaction is a commonly used calibration standard for neutron-induced reactions and has recently attracted much theoretical attention as a means of inferring the πNN strong-interaction coupling constant (recent values of which differ by 5 standard deviations from previous work). Although this fundamental cross section should be well known, recent measurements of the cross section near 0° have differed substantially from earlier measurements at 95 and 162 MeV. During the 1994 beam cycle, members of P-23 measured this cross section from 50 to 250 MeV over three angle ranges up to a 50° proton angle in the laboratory (approximately 80° in the center of mass). The data are currently being analyzed.

In the decades-old study of cosmic radiation, the source(s) of energetic rays above about 1 GeV has not been identified. Because charged particles are deflected in the galactic magnetic field, gamma rays are potential indicators of localized cosmic-ray sources. Charged particles and gamma rays interact in Earth's atmosphere and dissipate their energy by creating a cascade, or air shower, of secondary particles. As the air shower progresses through the atmosphere, the number of charged particles and gamma-rays increases, and the energy per particle decreases. In collaboration with colleagues internal and external to the Laboratory, P-23 has been operating an air-shower detector called CYGNUS to measure charged cosmic rays and gamma rays in the energy range around 10^{14} eV. Over the past several years, P-23 has also led the development of a new-generation air-shower detector, known as MILAGRO, which will detect Cerenkov radiation (light) produced by incident air-shower particles. MILAGRO will be particularly suited for the study of episodic or transient gamma-ray sources (*i.e.*, for recording gamma-ray bursts).

Historically, a major portion of the effort of P-23 has been in the acquisition and analysis of data from tests of nuclear explosive devices in underground shots at the Department of Energy's (DOE) Nevada Test Site (NTS). P-23 had the responsibility of measuring escaping neutrons and of analyzing data to compare measured energy spectra, time-history emission, and spatial distribution of neutrons with the results of device-performance calculations. The detecting instrumentation developed for nuclear-explosive-device diagnostics must be remotely operated and reliable in the hostile environment of an underground nuclear test shot. Recording instrumentation includes large-format, streak and intensified, fast-scan video cameras; image-data-capture systems; fiber-optic, data-transmission links; high-sensitivity, mega-sample rate digitizers; and gigahertz-oscilloscope, data-recording systems.

Los Alamos has acquired much data on the performance of nuclear devices over the years. With the cessation of nuclear testing and with the charge of the Scientific-Based Stockpile Stewardship (SBSS) to certify the performance of weapons in the stockpile, these data are crucial to the improvement of the physical models and to the certification of new computer codes describing the performance of nuclear devices. Although data from underground test shots between 1964 and 1992 have been reduced and informally reported for each test, records and analytical results have not been documented in a form accessible by technical personnel who were not directly engaged in the experiments. The information that P-23 is responsible for concentrates on precision measurements of neutron leakage and on imaging sources of radiation produced by nuclear devices. Members of P-23 are engaged in collecting the data and other pertinent parameters and in storing them in a logical structure in a computer archive. This work often involves the reanalysis of experiments. The archives will include files describing the experiments in detail with all information to compare calculations of device output with the experiments. Procedure files are written to guide the user of the data through the necessary steps to perform the calculations. P-23 has assembled a network of computing equipment originally required for storage and analysis of data from underground tests and is currently creating an “archive” of data from underground nuclear test shots in an accessible format. Group members are also writing handbooks about the experiments, *i.e.*, history, design, analysis, and interpretation, to preserve group members corporate knowledge for the future.

With the cessation of nuclear testing, P-23 is also providing state-of-the-art imaging capabilities and high-precision and high-sensitivity measurement capabilities as part of the AGEX and the UGEX (underground experiments) programs. As part of AGEX II, for example, P-23’s data-acquisition and -analysis work has been essential in studying the physics of electromagnetically driven implosions. The quest to achieve controlled thermonuclear fusion has evolved into two mainline approaches: magnetic fusion energy (MFE) as embodied in tokamaks and inertial confinement fusion (ICF). Approximately 10 orders of magnitude in density, pressure, and time scales separate each approach from the other. Intermediate between MFE and ICF in time and density scales is an area of research known in Russia as “magnitnoye obzhatiye,” or MAGO, and in the U.S. as magnetized target fusion (MTF). MAGO / MTF uses a magnetic field and a preheated, wall-confined plasma within a fusion target. The magnetic field suppresses thermal conduction losses in the fuel during the target implosion and the hydrodynamic-compression-heating process. In a collaboration developed over the past few years between researchers at Los Alamos and at VNIIEF, the premier Russian nuclear weapons laboratory located at Arzamas-16, researchers have examined various MAGO / MTF schemes in an historic program that involved experiments performed at both institutions. P-23 has measured neutron flux and has imaged the neutron source distribution using technology developed at NTS.

P-23 has also provided instrumentation and recorded and analyzed data for a number of AGEX II tests at the Los Alamos Pegasus II and Procyon facilities. The experiments consist of recording the motion of assemblies imploded by magnetic forces. An imploding pressure is generated by passing the current from a capacitor bank through an annular conductor within which a test object is placed. Currents of sufficient magnitude are available to reach pressures that cause implosion of test objects representing nuclear systems. Records of implosions include optical images of the external structures and x-ray images of internal test objects. Our group provided cameras and timing circuitry that were needed to achieve a number of images for each experiment and that had sufficient spatial and temporal resolution to record the dynamics of the implosions. Instrumentation developed in our group for diagnostic measurements of underground nuclear explosions was applied to AGEX II experiments so that the experimental program could proceed with little delay. During FY94, P-23 participated in fourteen experiments at the Pegasus II Facility and two experiments at the Procyon Facility. The phenomena observed by P-23 included radiation flow, liner ejecta, and liner gap. Diagnostic instrumentation provided by P-23 included visible-image, holographic-image, and x-ray-image recorders.

Applied Technology

P-23's applied technology efforts include the development of an optical-fiber implementation of quantum cryptography (*i.e.*, the science of secret communications), which uses single-photon interference at a 1.3-μm wavelength to compare and distill a shared, secret subset of bits (the key material) from initial, independent random number sets generated by a sender and a recipient (Fig. 2). Members of P-23 have demonstrated "key distribution" in a laboratory environment and in FY95 expect to establish a demonstration quantum cryptographic link over installed optical fibers between two Los Alamos technical areas

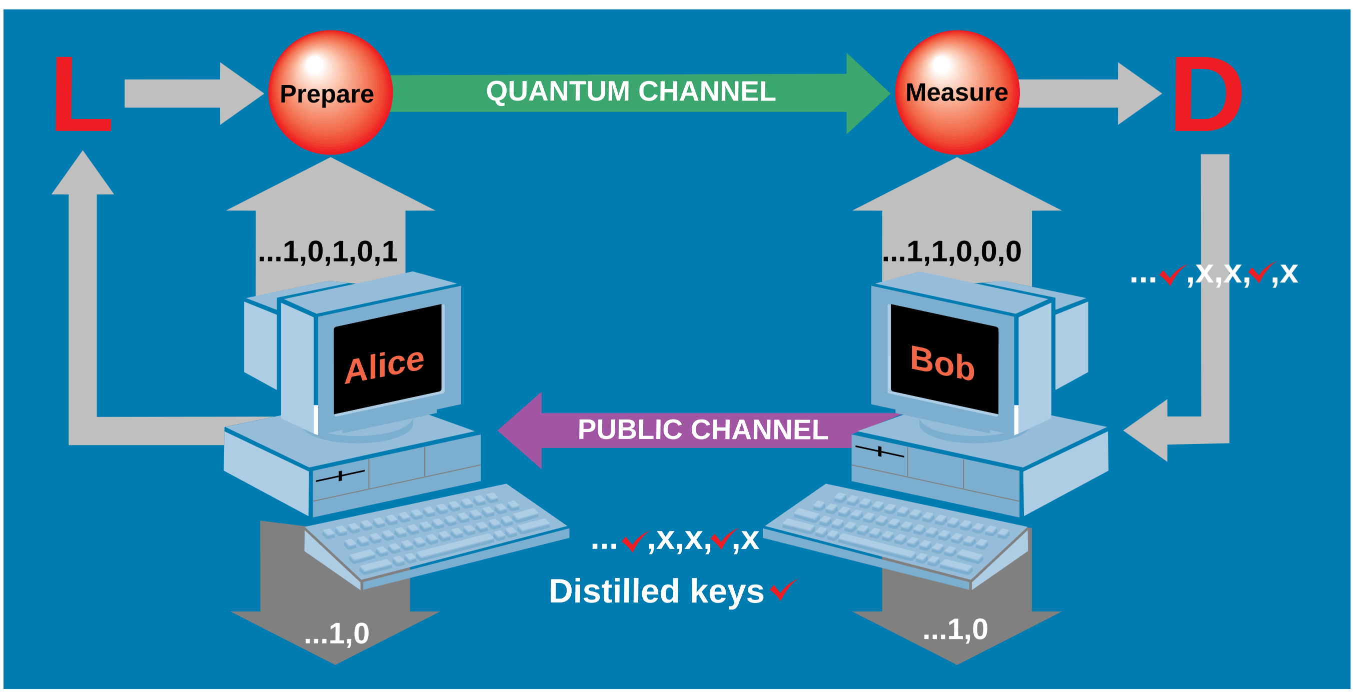


Fig. 2. Alice and Bob begin quantum key distribution by producing their own independent sets of random binary numbers. From these two distinct sets, they distill a common shared set. Alice begins by preparing a single photon in one of two ways with her laser source (L), depending on whether the number is a 0 or a 1. Each prepared photon is sent over the quantum channel to Bob, who makes measurements in synchronization with Alice's preparations. A photon will only trigger Bob's detector (D) if their numbers are the same. Bob labels these numbers from his set as "hits" (✓) and passes the labels (but not the numbers) on to Alice over the public channel. The "hits" form the shared secret key.

separated by a distance of 7.5 km. This work has led to initiatives in quantum computing as well.

As part of its effort in advancing the state of the art in high-speed cameras for recording data from weapons tests and now UGEXs and AGEXs, P-23 has developed (and filed patent application on) a test facility unique in the U.S. Present cameras use charge-coupled devices (CCDs) that have 244- x 256-pixel arrays, can record up to 1,000 frames per second (with a data rate of 50,000,000 pixels per second), and are capable of shutter-time intervals in the nanosecond range. A camera developed at Los Alamos was demonstrated at the Henry Ford Hospital, Detroit, Michigan, as a candidate for incorporation into a system capable of diagnosing animal and human joints in action and under stress, *e.g.*, runners' knee joints.

In addition, a P-23-developed camera was delivered to the U.S. Navy as part of an experimental system onboard an aircraft. This experimental system will have the capability of detecting mines placed in surf zones. The mine-detection project involves the development of a range-gated video system for the Marine Corps for detecting mines in shallow sea waters on prospective assault beach fronts. The system was successfully deployed by a Los Alamos and a U.S. Navy Coastal System Station (CSS) team in the field at the CSS in Panama City, Florida. The PIER TEST phase of the video system in the Bahama Islands is scheduled for 1995. Members of P-23 also conducted tests on several CCDs and charge-injected devices to study permanent damage thresholds from accumulated doses of ionizing radiation. This project was funded by the Laboratory's Industrial Partnership Office (IPO) under the Small Business Initiative Program. Sensors were exposed to different flux levels to produce a total given dose at different rates to study optical sensitivity as functions of both absorbed dose, as well as dose rate involved in the exposures. This P-23 work involves on-going research as new radiation-hardened devices that can withstand Mrad doses are developed. In addition, P-23 is involved in the refinement of earlier efforts to develop transmission-line gating techniques for modified proximity-focused microchannel-plate image intensifiers, which incorporate stripline geometry designed by P-23 and fabricated by RTC Philips, Inc.

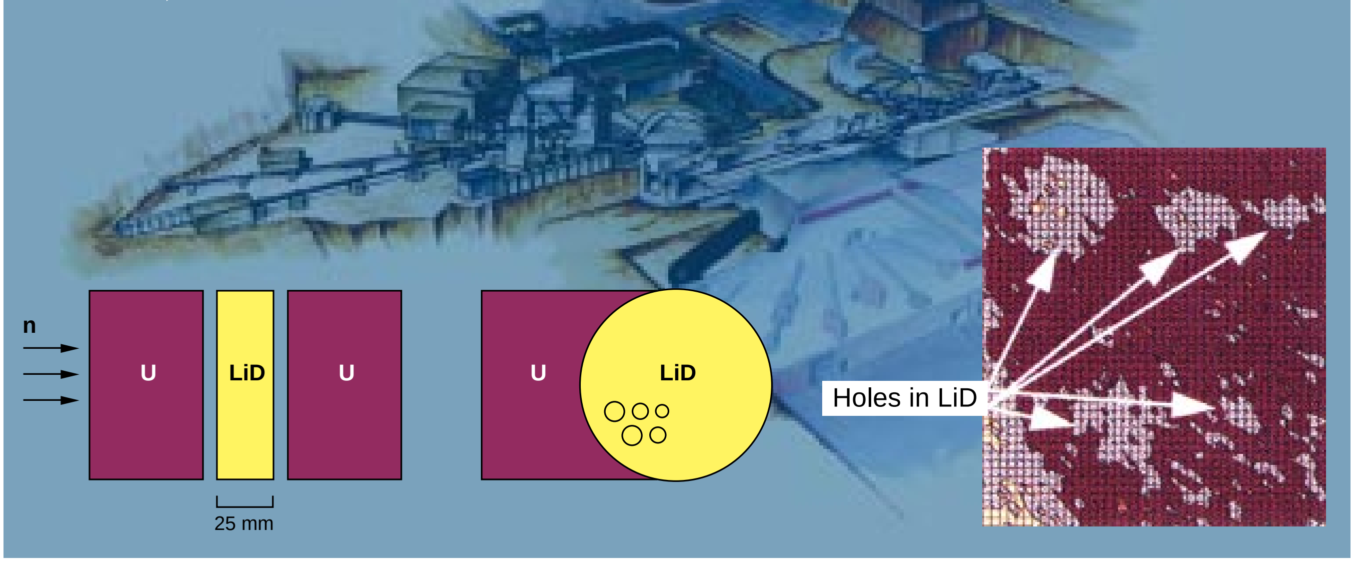
P-23 has the ability to record transient and imaging data at remote locations using a mobile recording facility known as the "Piranha Van," a 26-ft delivery van that has been modified by EG&G Energy Measurements, Inc., to house a state-of-the-art digital recording system. During the last year, the Piranha Van has been used to record data from experiments at the Trident laser facility and from experiments at several high-explosive test sites.

The IBF produced general-purpose, precision ion beams for a wide variety of users and experiments. Resources at the facility included a vertical Van de Graaff accelerator capable of operating at potentials up to 8 MeV and an HVEC model FN tandem Van de Graaff accelerator operating up to 11 MeV. The vertical accelerator provided extremely stable low-energy ion beams. Coupling it to the FN tandem resulted in a unique, high-energy ion beam. Its precision neutron- and ion-production capabilities had been regularly used by P-23 to develop and calibrate detectors for nuclear-explosive-device diagnostics.

The WNR Facility includes a building that houses a target (Target 4) into which an 800-MeV proton beam from LAMPF is directed. The protons, delivered in pulses that are separated in time by a few microseconds, generate neutrons by a spallation process of tungsten from the target. Five flight paths for the spallation neutrons are provided at different angles from the direction of the proton beam. Experimental equipment is located along the flight paths at distances up to about 50 m from the target. The energy spectrum of the spallation neutrons has been used over the range of 0.1 to 600 MeV, although energies up to 800 MeV are available. At any position along a flight path, neutrons in a chosen energy interval are selected by restricting observation to a prescribed interval.

At the WNR Facility, members of P-23 are evaluating the use of high-energy (up to 800-MeV) neutron beams for imaging light materials embedded in thick, heavy materials with a technique known as neutron radiology (Fig. 3). X-rays, widely used for radiography, have a very poor contrast for low-Z materials as compared with high-Z materials. Neutrons are scattered and thus removed from a beam more readily by low-Z elements as compared with x-rays, thus providing a better contrast for light materials. Although slow neutron radiography has been used for many years as a nondestructive testing technique, the use of higher-energy neutrons is a novel concept. P-23's neutron radiographic technique has potential important applications in nuclear-weapons stockpile surveillance.

Fig. 3. First images of a perforated LiD slug (imbedded between two uranium slabs) produced with the WNR facility (background illustration) neutron beam.



In support of the accelerator production of tritium (APT) program, P-23 is participating in a number of investigations related to the physics of a target/blanket system. Members of P-23 are measuring the total neutron production and tritium production by 800-MeV protons in a benchmark target assembly at the WNR Facility. Diagnostic instrumentation is being developed to monitor neutron and tritium production in a full-scale target assembly to be tested in 1998. In addition, group members are conducting supplementary experiments to measure total neutron production as a function of proton energy on lead and tungsten targets at the Saturne accelerator in Saclay, France. Work is also in progress on the production of radionuclides by high-energy protons in targets of lead, tungsten, iron, and aluminum. These data are important to benchmark the computer code system LAHET/MCNP, which is used to predict inventories of radionuclides in the target and coolant systems. The WNR Facility will also be used to develop imaging systems capable of diagnosing the performance of the APT beam-expander system, which will be used to characterize a prototypic beam expander.

As part of the Comprehensive (Nuclear Weapon) Test Ban Treaty, P-23 has been instrumental in an experimental program aimed at monitoring clandestine underground nuclear explosions. One technique currently under consideration is the detection and recording of acoustic waves generated in the atmosphere. The Air Force Technical Applications Center (AFTAC) operates a U.S. monitoring system that includes a facility known as the National Data Center (NDC). The NDC receives and evaluates all information from ground-based and satellite stations that comprise what is known as the National Technical Means (NTM) for treaty monitoring. An “infrasound” detector, a type of microphone that picks up frequency bands below the audible range, is presently under consideration for inclusion as part of the NTM system. Three microphone stations have been installed in Los Alamos, the NTS, and southern Utah. During 1994, P-23 implemented a high-speed data link between Los Alamos and the AFTAC and provided hardware and software so that data recorded by the microphones from the three stations could be transmitted continuously to the NDC over dedicated telephone lines.

P-24: Plasma Physics

Kurt Schoenberg, Group Leader
Juan Fernandez, Deputy Group Leader

Introduction

Group P-24, Plasma Physics, applies an extensive knowledge of plasma physics, atomic physics, laser-matter-interaction physics, pulsed-power technology, and laboratory-based experiments to study matter in the plasma state. Plasmas occur in nature when matter exceeds temperatures of roughly 10,000°C. At these temperatures, the constituent atoms and molecules of matter begin to lose their bound electrons to form a substance composed of positive or negative ions and free electrons. All principal phenomena in plasmas can be traced to the fact that ions and electrons interact with each other by long-range electromagnetic forces. The electromagnetic interactions of groups of charged particles are often coherent, leading to collective modes of plasma behavior. This collective interaction of charged particles, a many-body problem, is the essence of the field of plasma physics.

Roughly 99% of the matter in the universe is in a plasma state. Plasmas can exist over a large range of temperatures and densities (Fig. 1). For example, interstellar space contains plasmas with densities of less than one ion or electron per cubic meter at a temperature exceeding 1,000°C. Contrast this to plasmas created by intense laser compression of micropellets that achieve densities of 10^{24} per cubic centimeter at temperatures exceeding 10,000,000°C. The understanding and application of such diverse plasmas is the gestalt of plasma physics.

P-24 addresses problems of national significance in inertial and magnetic fusion, nuclear weapons stewardship, conventional defense, environmental management, and plasma-based advanced manufacturing. Our agenda includes basic research in the properties of energetic matter and applied research that supports the principal Los Alamos National Laboratory mission of reducing the nuclear danger. As shown in Fig. 1, and discussed below, the pursuit of this agenda entails the physics of plasmas over a wide and diverse range of conditions.

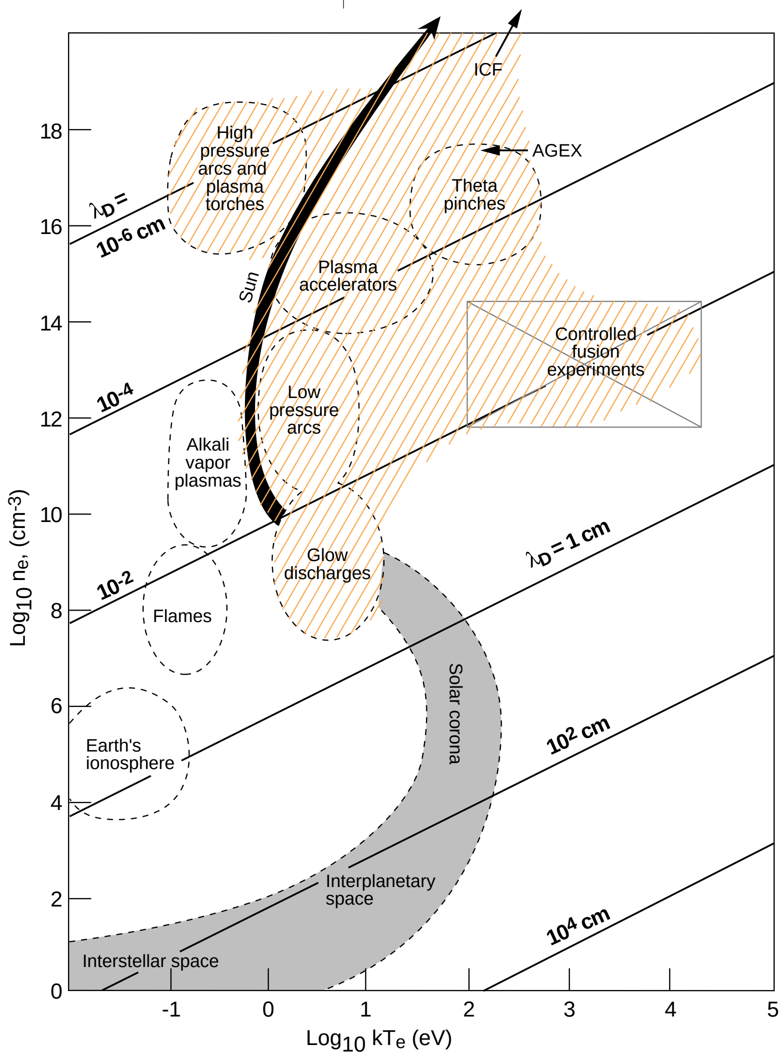


Fig. 1. Range of plasma temperatures and densities. The shaded orange region shows the regime of P-24 research. λ_D defines the fundamental scale length for plasma interactions.

Scientific-Based Stockpile Stewardship

A crucial challenge in Scientific-Based Stockpile Stewardship (SBSS) is that of understanding weapons-physics issues in the absence of nuclear testing. Much of weapons science depends on detailed studies of hydrodynamics or radiation physics at energy densities greater than those that can be obtained in explosively driven experiments. Pulsed-power-driven or laser-driven experiments enable us to access physics regimes and phenomena associated with both weapon primaries and secondaries. In these high-energy-density regimes, an understanding of plasma behavior is important in creating the high-energy-density state and in understanding phenomena associated with high-energy-density matter. In this venture, we use the Nova laser at Lawrence Livermore National Laboratory (LLNL) to study hydrodynamics, implosion symmetry, and radiation transport as related to weapons issues. We team with other P- and X-Division groups in conducting experiments on the Pegasus capacitively driven implosion facility. We also participate in the design of Atlas, the next-generation pulsed-power implosion experiment.

Inertial Confinement Fusion

The inertial confinement fusion (ICF) program at Los Alamos is a principal player in the national goal to achieve thermonuclear ignition in the laboratory. In pursuit of this mission, P-24 designs, executes, and analyzes experiments on high-energy laser facilities worldwide. In this effort, we team with theory and modeling efforts to understand the dynamics of intense laser-matter interaction physics.

Great advances in laser technology have enabled the compression of micropellets to very high temperatures and densities. The promise now exists for the thermonuclear ignition of deuterium-tritium pellets with the proposed 1.8-MJ National Ignition Facility (NIF). The NIF is also expected to play a fundamental role in the study and simulation of weapons physics as part of a national effort in SBSS.

The interpretation of next-generation laser experiments on facilities like NIF depend on an accurate understanding of laser-plasma and laser-matter interactions. Here the control of collective effects in laser-heated plasmas, implosion symmetry, and hydrodynamic instabilities in convergent geometry is crucial. Los Alamos has had a key role in furthering the science and technology in these areas.

In the past year, our research using the Nova laser at LLNL addressed collective laser-plasma effects by investigating the backscatter of laser light by plasma parametric instabilities. We fielded the first gas-filled hohlraum experiments to address symmetry and hohlraum-ablation issues for the NIF. We pioneered a new technique for analyzing the stability of imploding capsules and applied this technique to Nova- and NIF-relevant implosions. We also continue to develop state-of-the-art diagnostics in pursuit of our target-physics program.

Our Trident laser continues to play an important role in ICF target physics. In the past year, we executed 850 target-physics shots that yielded excellent results on issues such as plasma instabilities and foam smoothing of laser beams. This work has demonstrated our philosophy of using Trident as a low-cost, fast-turn-around staging and development facility where new instruments and measurement techniques can be developed, prototyped, and calibrated.

Magnetic Confinement Fusion

Los Alamos scientists have been engaged in fusion research since the inception of the program in the early 1950s. Today, all experimental magnetic fusion research at Los Alamos resides in P-24. Our research is focused in two main thrust areas: (1) using neutron- and fusion-product diagnostics to measure the fusion power output from burning plasmas and (2) controlling so-called “major disruptions” in tokamak plasma-confinement devices.

Our participation in the deuterium-tritium physics program at the Tokamak Fusion Test Reactor (TFTR) at Princeton Plasma Physics Laboratory has provided us with opportunities to develop and test neutron- and fusion-product detectors for burning plasmas. The expertise developed on the TFTR program is now being applied to the needs of the International Thermonuclear Experimental Reactor (ITER) in investigating ways to measure its fusion power output.

Our capabilities in advanced diagnostics, as well as measurements in complex experiments, are being applied to the problem of major disruptions in tokamaks. Fast imaging systems that are sensitive to plasma emissions from infrared to hard x-ray sources are being developed for present experiments and for eventual use in the tokamak physics experiment (TPX). In other collaborations, we have designed, built, tested, and fielded detectors made of an array of many thread-like scintillating optical fibers spaced apart in an aluminum holder. A compact scintillating-fiber detector, known as “Sci-Fi,” detects 14-MeV neutrons—the by-products of the fusion reaction. Sci-Fi is a two-channel system installed on the JT-60U tokamak experiment in Japan, where it is providing spatial resolution with the fastest-ever time response in the physics of fast-ion confinement (Fig. 2).

Fig. 2. View of inside of JT-60U Tokamak at Naka Fusion Establishment, Japan. Los Alamos diagnostics for 14-MeV neutrons are used in a collaboration on fusion physics.

Historically, we have had significant involvement in developing compact, advanced, high-plasma-pressure alternatives to conventional tokamak concepts. We are applying hardware and knowledge developed from those alternative-concept programs to the control of destructive plasma instabilities in tokamaks. In collaboration with Columbia University on their high-beta tokamak, we have built and tested a feedback-controlled power supply that will control instabilities in the plasma at high plasma pressure. This work is critical to the operation of advanced tokamaks and will lead to a feedback system for controlling disruptions for the proposed TPX at Princeton University.

In the past year, we have successfully developed an extremely intense diagnostic neutral beam to penetrate the large, hot, dense plasmas expected in the ITER, which uses a pulsed-power ion-diode source to deliver 10,000 A of ions at 80,000 V. After the electrical charge of the ion beam is neutralized, the beam provides a source of neutral atoms deep within the plasma for specialized-plasma-diagnostic measurements of ion temperature, current profile, and alpha particles. This device has shown that a high-current-density ion beam can be neutralized in a gas cell and turned into a neutral beam for the subsequent injection into a tokamak. This is an “enabling technology” for a future large-scale ion beams for the ITER.

Applied Plasma Technologies

The future health of the U.S. economy requires an American industry that is internationally competitive, energy efficient, nonpolluting, and capable of manufacturing a wide array of products with unprecedented performance. Advanced-plasma technologies can help make this a reality. The energetic nature of plasmas is ideal for materials synthesis, material joining, material fabrication, and surface- or bulk-property modification. Advantages over conventional manufacturing techniques include dry processing to minimize waste and hazardous chemicals, local deposition of energy to minimize energy use and avoid the harmful bulk heating of materials, and high-temperature or nonequilibrium processes that enable the manufacturing of materials and products with dramatically improved performance.

We are exploring a wide range of plasma technologies (Figs. 3a, b, and c) with direct applications to both industry and weapons-stockpile surety. We developed and currently operate the largest plasma-source ion implantation (PSII) facility in the world, a device used to harden the surfaces of various materials, such as machine tooling, to increase their durability. Our PSII effort includes the largest CRADA at Los Alamos, a four-year $14 million joint venture with General Motors Corporation initiated in 1992. Other activities include other CRADAs, technical consulting agreements, and work-for-other research and development with Litton Electron Devices, Empire Chrome, Kodak, Black and Decker, Videojet Systems, Jasco Tools, Burkhardt America, and A.O. Smith. Our PSII Facility was designated as a Department of Energy (DOE) users facility in 1994 to provide more flexible and timely response to industrial partners' requests.

Fig. 3a. Schematic of inductive plasma torch (below) and image of oxygen plasma jet produced by a 600-kW rf torch (right).

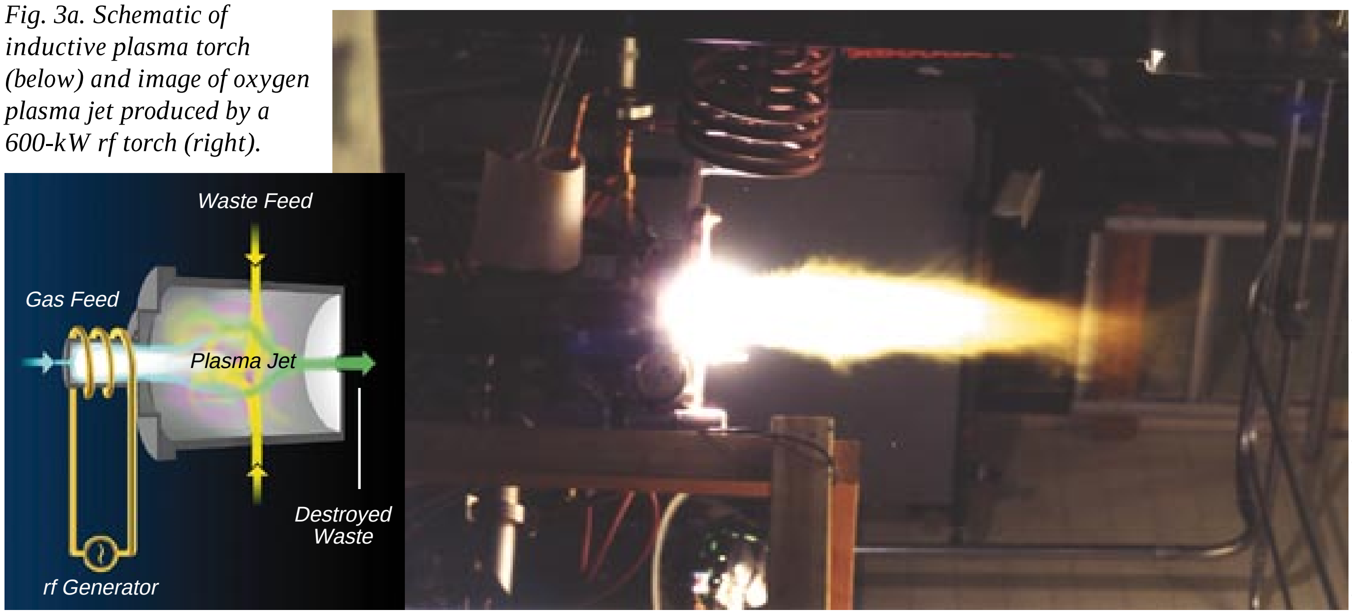
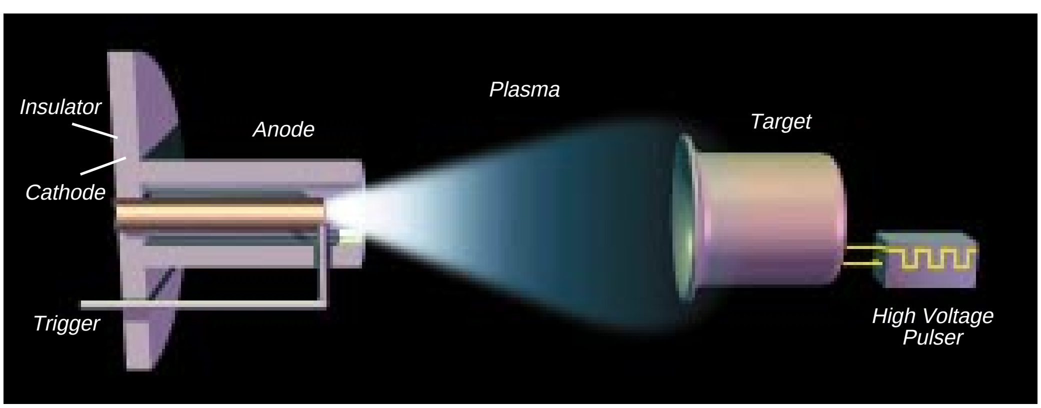


Photo courtesy of Plasma Technology, Inc., Santa Fe, NM

We are actively working with the semiconductor industry in areas of future technology needs in which we have (1) a highly unique and well-recognized worldwide leadership or (2) a complementary direction and need for established Laboratory, DOE, or Department of Defense missions—the dual-benefit requirement. Our current program in detection, control, and understanding of particulate contamination in plasma processing is an example of the first criterion. This program supports U.S. leadership in this key technology and strengthens other Los Alamos programs in plasma applications, such as plasma etching as a means for environmental remediation and reclamation and for environmentally responsible weapons manufacturing (*i.e.*, the second criterion).

Fig. 3b. Pulse biasing a target increases the adherence of metal and metal-oxide coatings deposited from a cathodic-arc-derived metal ion plasma.



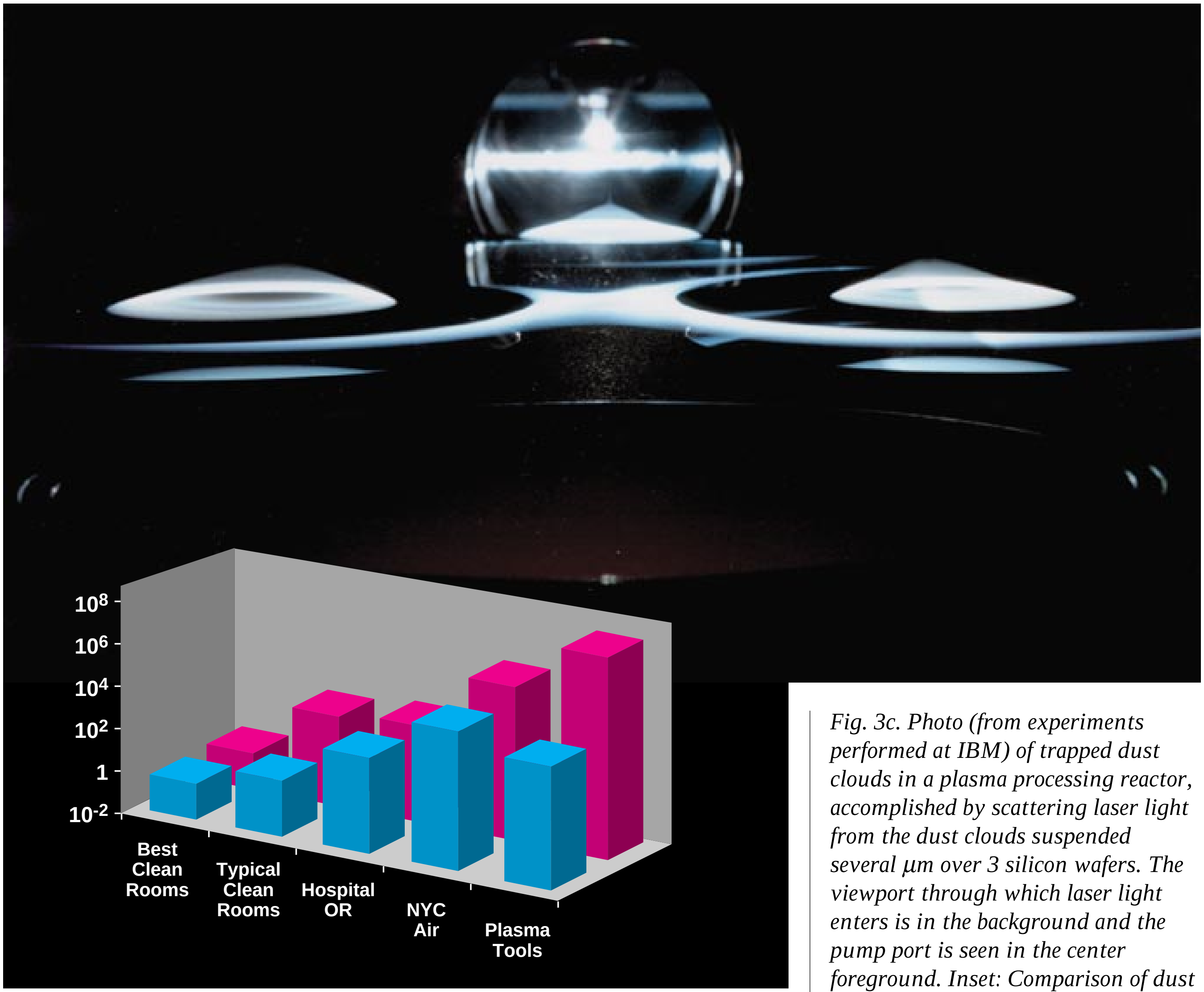


Fig. 3c. Photo (from experiments performed at IBM) of trapped dust clouds in a plasma processing reactor, accomplished by scattering laser light from the dust clouds suspended several μm over 3 silicon wafers. The viewport through which laser light enters is in the background and the pump port is seen in the center foreground. Inset: Comparison of dust density (blue: lower range, purple: upper range) for different environments. Note the average dust density in plasma tools exceeds the average dust density for New York City air.

Future private-sector market segments that will be impacted by plasma technologies are enormous. For example, nearly 35% of the process steps involved in the multibillion dollar fabrication of semiconductor devices now involves plasmas. This percentage is likely to grow as plasmas are used for environmentally benign cleaning and particulate control during manufacturing. P-24 will continue to lead Los Alamos development of plasma processing with dual-benefit industrial applications.

Special Projects

Hypervelocity interceptors address the emerging need to interdict hostile theater ballistic missiles before the release of submunitioned warheads. Of central importance to hypervelocity missile design is understanding missile performance in the severe operational regimes of interest. We continue to consult with the Ballistic Missile Defense Organization in hypervelocity technology applications.

P-25: Subatomic Physics

John McClelland, Group Leader
Andrea Palounek, Deputy Group Leader

Introduction

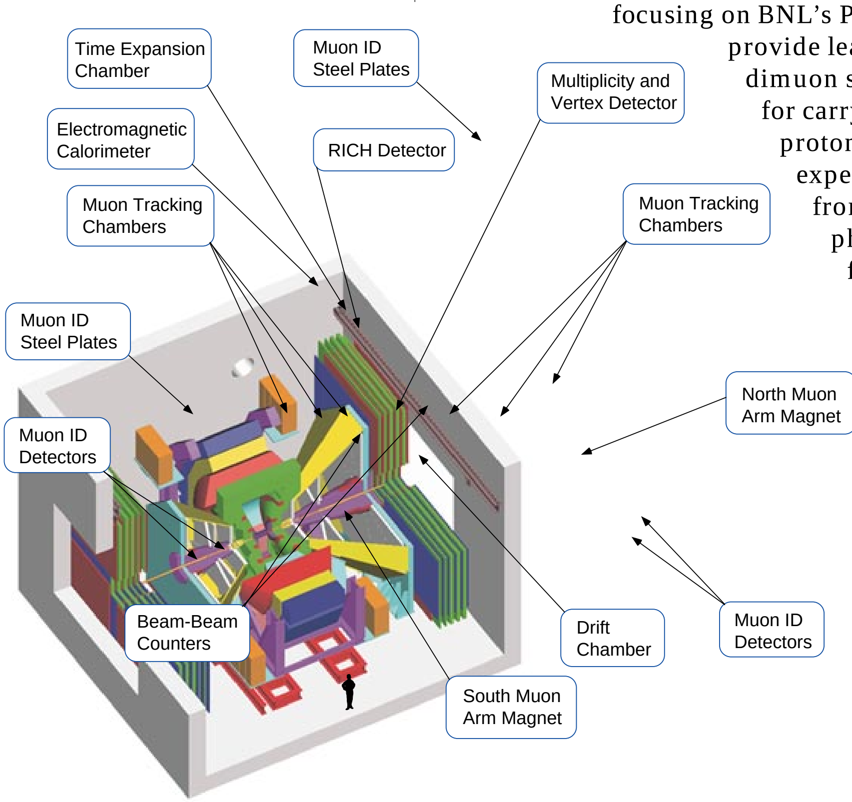
Group P-25, Subatomic Physics, is primarily engaged in nuclear and particle physics research. There is also a growing effort to turn the group's skills and capabilities to applied programs within the Physics Division, such as neutron radiography. The group currently has roughly equal efforts at the Los Alamos Meson Physics Facility (LAMPF) and at laboratories outside Los Alamos. The LAMPF-related program will diminish after FY95; work is under way to integrate this effort into existing Physics Division programs and to develop new programs both at Los Alamos and at other laboratories, including Brookhaven National Laboratory (BNL) and Fermi National Accelerator Laboratory (FNAL). The people and programs in this group were highly rated in a recent nationwide review of the DOE nuclear physics program. Highlights of P-25's activities and future directions are below.

Quark/Gluon Physics

The quark / gluon physics program has been highly visible and productive at FNAL. Our group was the first to exploit high-energy hadronic processes to explore the quark structure of nuclei. We are investigating the nuclear dependence of lepton-pair production with proton beams to understand how the quark and gluon structure in nuclei differs from that in free nucleons. The group is preparing to run an experiment during the next fixed-target operation at FNAL to search for deviations in the anti-up and -down quark distributions in the proton to provide insight into hadronic and partonic descriptions of the nucleonic "sea."

In the future, the Relativistic Heavy Ion Collider (RHIC) at BNL will provide the opportunity to explore quark and gluon structure in nucleons and nuclei in new kinematic regimes through proton-proton reactions, proton-nucleus reactions, and polarized-beam reactions. The group is focusing on BNL's PHENIX detector (Fig. 1) at RHIC to provide leadership in these investigations. The dimuon spectrometer is particularly well suited for carrying out a program of high-energy proton-nucleus and polarized-beam physics experiments that are a natural evolution from the FNAL program. The polarized physics program at RHIC is being facilitated by a new collaboration between Los Alamos and RIKEN, which is the Institute of Physical and Chemical Research in Japan. Polarized-beam physics, which is also being investigated at FNAL, might draw on P-25's expertise in laser-driven polarized sources and targets.

Fig. 1. A schematic cutaway view of the PHENIX detector.



Relativistic Heavy Ions

Group members are involved in the study of nuclear matter at high energy densities and in the search for a new state where quarks and gluons are deconfined; this state is called the quark-gluon plasma. This group made some of the first measurements of transverse energy flow and particle production in heavy-ion interactions and pioneered the use of event generators to construct correlation functions as a tool to diagnose the interaction region. P-25 has been involved in a number of heavy-ion physics experiments at the European Laboratory for Particle Physics (CERN) (HELIOS and NA44) and at Brookhaven (E814). P-25 is also playing a lead role in an experiment on the PHENIX detector now under construction at RHIC. We are responsible for the silicon Multiplicity Vertex Detector (MVD), the on-line software development, and the muon spectrometer subsystem. The new collaborative effort between RIKEN in Japan and Los Alamos will not only create a polarized-physics program at RHIC but will also greatly increase the relativistic heavy-ion program of the PHENIX detector.

The results from the Brookhaven and CERN experiments underscore the extent of interaction of potential quark matter signals with the surrounding hadronic matter. These issues are related to LAMPF physics, which characterizes the interaction of mesons with cold nuclear matter. We believe that some of the theoretical approaches used at LAMPF may aid in understanding heavy-ion studies.

Hadron Physics

Group members have recently completed the construction of the Neutral Meson Spectrometer (NMS), which is currently in use at LAMPF. This spectrometer will allow for large solid-angle particle detection with excellent energy resolution. Precision measurements of pion single-charge exchange are currently being made with the NMS to study pion-nucleon physics, nuclear structure, and reaction mechanisms. Our group has also led an effort at the high-energy pion channel (P3) to characterize the transport of pions in the nuclear medium; this work is essential to the interpretation of similar experiments conducted at the Continuous Electron Beam Accelerator Facility (CEBAF) in Virginia and at RHIC. Plans are under way to move the NMS, and possibly other LAMPF detector systems, to the alternating-gradient synchrotron at BNL to mount a new set of high-resolution hypernuclear experiments. In addition, group members are discussing participation in the first hypernuclear experiments to be performed at CEBAF.

Fig. 2a. Vern Sandberg of P-25 checks instrumentation in the interior of the electronics hut before an LSND experimental run. The purple modules in the background measure the time and charge of each phototube signal, and the colored lights on the front panels indicate the rate of phototube hits. The gray power supplies on the right provide high voltage for all the phototubes in the detector.

Electroweak Physics

The Liquid Scintillator Neutrino Detector (LSND), commissioned in 1993, has found evidence for neutrino oscillations (Figs. 2a and b). Group members are trying to identify the strange quark contribution to the proton’s spin by measuring neutrino-proton elastic scattering.

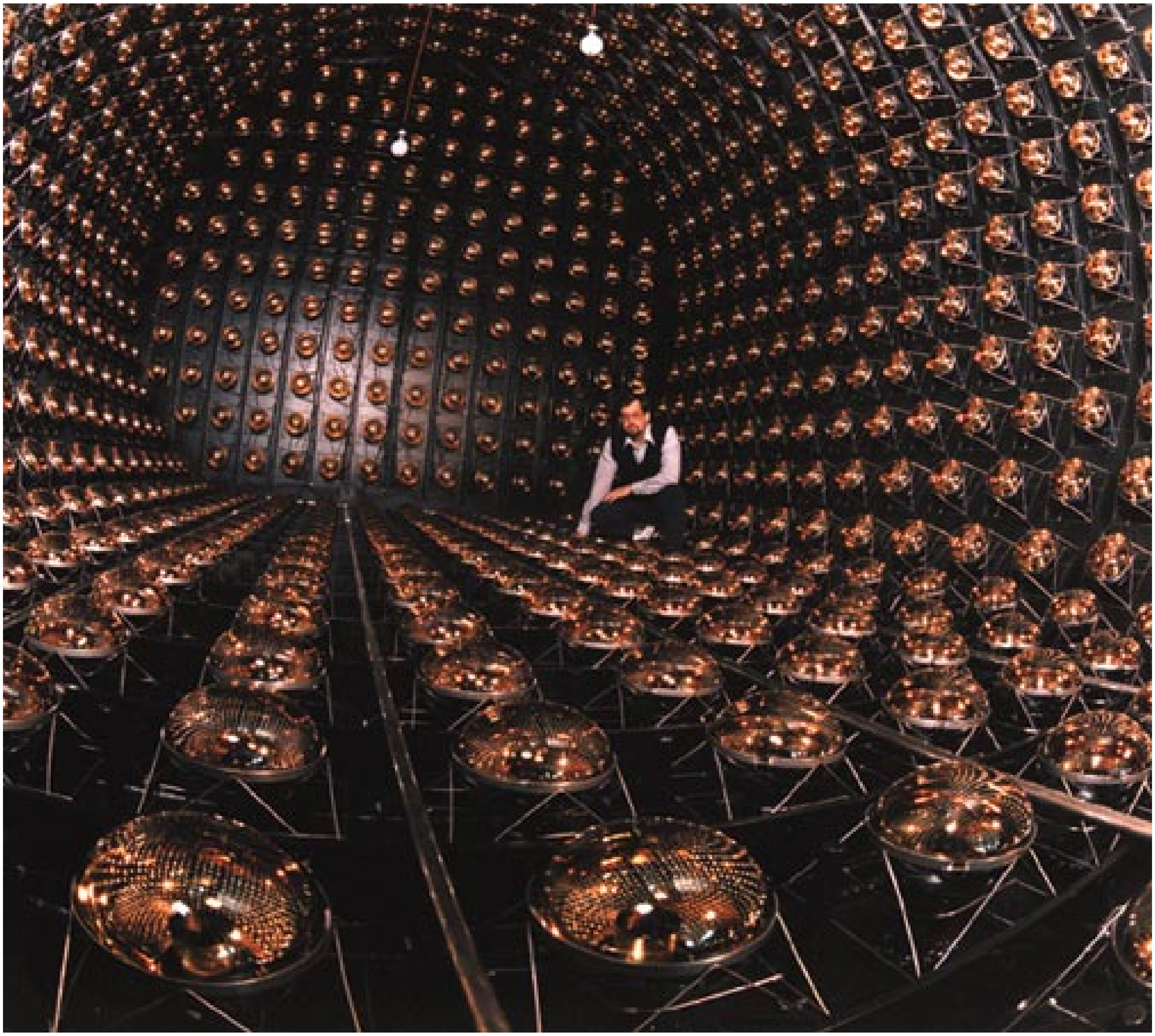


Fig. 2b. The interior view of the LSND shows a portion of the 1,228 phototubes that cover the inside of the tank. The LSND is filled with 200 tons of mineral oil and a low concentration of scintillator material to detect both Cerenkov light and scintillation light.

The LSND experiment will run for several more years to lend statistical weight to the results and to further analyze possible sources of spurious signals. The definitive experimental establishment of nonzero neutrino mass will have far-ranging impact into other fields, such as astrophysics. The present evidence suggests a strong need for follow-up experiments at FNAL.

MEGA [**M**uon (decays to) an **E**lectron and a **GA**mma ray] is looking for new physics beyond the Standard Model in the rare decay of the muon into an electron and gamma. This reaction, which has not been observed, sets one of the most stringent limits on lepton-family number conservation. These measurements will be completed by the end of the FY95 running period at LAMPF; two additional months of running at the start of FY96 may be possible. The experiment should set a limit of better than 10^{-12} on the branching ratio for this reaction (unless, of course, they observe the reaction).

Members of P-25 are also preparing to test the Standard Model by determining the weak charge Q_W, which is accessible through precise measurements of atomic-parity-nonconserving (PNC) transitions in a wide range of cesium isotopes. They have produced high-intensity cesium radioisotopes and have trapped them from a gas vapor. The PNC group is preparing the mass separation and subsequent trapping of radioactive cesium to produce a concentrated, fully polarized cold source of cesium atoms.

P-25 is considering options to mount the next-generation neutrino detector at FNAL or BNL to undertake a precise measurement of muon decay parameters at TRIUMF (the Tri-Universities Meson Physics Facility / Factory in British Columbia, Canada) and is looking at opportunities in neutron physics at the (Manuel Lujan) Los Alamos Neutron Scattering Center.

High-Energy Physics

Group members have been involved in the recently completed rare-kaon-decay experiment at Brookhaven (E791) and were also involved in the experiment proposals for the GEM (**G**amma, **E**lectron, and **M**uon) detector and the Solenoidal Detector Collaboration at the Superconducting Super Collider (SSC). Members of P-25 are involved in the current running of the L3 experiment at CERN and have taken a lead role in upgrading that detector. This group is evaluating options for their silicon-tracking expertise on the Compact Muon Solenoid at the CERN Large Hadron Collider and for gamma-ray detection using detectors flown on satellites.

Applied Technologies

The group has an effort in some applied technologies, including quantum cryptography and neutron radiography. Neutron radiography detects irregularities in thick, heavy materials and in light materials embedded in the heavy materials. Our experience and expertise in particle detection enabled us to take existing components and construct a detector to test the basic concepts of high-energy neutron radiography at the WNR Facility. In our quantum cryptography work, we have contributed to experiments that demonstrate key distribution through members' expertise in lasers. We anticipate that these types of applications will continue to grow in the future and take advantage of the skills and capabilities of the group in areas of vital interest to the Laboratory and the nation.

Experimental Technologies and Support

P-25 has expertise that can be directed toward a broad range of applications. We are expert in detector technologies that include wire-chamber, scintillator, and silicon-microstrip design and fabrication. We have used wire chambers and scintillators for a number of applications at LAMPF, including the NMS, the PHENIX muon-tracking-system prototype, and most recently the neutron-radiography measurement at the WNR Facility. We helped develop silicon tracking for the FNAL, CERN, and SSC programs and are presently applying it to the PHENIX MVD system at RHIC. The group also has considerable experience in the design and fabrication of a large, magnetic, neutral-particle detectors and electronics and data-acquisition systems. The group's highly skilled technician section has traditionally supported efforts at LAMPF and can now support large, complex experimental efforts throughout Physics Division.

Chapter Two *Research Highlights*

An assembly of 90 automotive pistons being treated in the P-24 Plasma Source Ion Implantation Facility as part of a CRADA with General Motors Research Laboratories.

Unexpected Features of Retinotopic Organization in Human Visual Cortex Revealed by Neuromagnetic Mapping

C. J. Aine, J. S. George, D. Ranken, W. Tiee, E. R. Flynn, C. C. Wood (P-21), E. Best (CIC-12), S. Supek (Faculty of Science, Physics Department, Zagreb, Croatia), J. Lewine, J. Sanders (Department of Radiology, University of New Mexico School of Medicine, Albuquerque, New Mexico)

A major goal of noninvasive studies of human vision is to identify and characterize the functions and arrangement of the neural systems involved in visual perception (*i.e.*, to map the brain). Invasive studies of vision in nonhuman primates have demonstrated the existence of multiple cortical regions, which respond to visual stimulation. Each of the cortical regions identified contains some representation of either a portion or the entire visual field and performs a special function (*e.g.*, to process color or motion). One criterion for identifying different visual areas in nonhuman primates is a demonstration of retinotopic organization in each area (*i.e.*, a point-to-point projection of the visual field onto the visual cortical areas). The boundaries of different visual areas within a single hemisphere may be outlined by focusing on the cortical representations of the vertical and horizontal meridians in the visual field because these locations typically project to the edges of cortical visual areas.

The classical model of retinotopic organization represents our current understanding of retinotopic organization of the primary visual cortex (V1) in humans. This model is based on clinical studies correlating the location and extent of lesions in the visual system with visual-field defects. According to the model, the representation of the horizontal meridian is at the base of the calcarine fissure (*e.g.*, see the arrow in the bottom portion of Fig. 2). Lower-field stimuli are expected to activate regions in the upper bank of the calcarine fissure and vice versa. In addition, there is a predicted systematic relationship between depths of sources in the calcarine fissure and the eccentricity of stimuli in the visual field (*i.e.*, peripherally placed stimuli activate regions deeper within the fissure region). A number of noninvasive brain-mapping techniques, including positron emission tomography (PET) and functional magnetic resonance imaging (fMRI), have been used to investigate the retinotopic organization of human V1. Both PET and fMRI measure changes in the hemodynamic or metabolic responses of the brain rather than directly measuring neural activity itself. However, the spatial/temporal resolution of PET and fMRI techniques cannot adequately distinguish the activity of V1 from the adjacent active regions because these techniques are limited by the slow timecourse of the hemodynamic response (~ 1 s).

At Los Alamos, we examined human V1 retinotopy using neuromagnetic measures combined with multisource, spatio-temporal modeling, and information about the anatomy of the calcarine region derived from magnetic resonance imaging (MRI). We have identified several different regions active during the initial 80- to 165-ms time interval following the onset of visual stimulation. Although our results support the general features of the classical model for V1, we observed significant departures from the classical model regarding the representation of the horizontal meridian in the depths of the calcarine fissure. In some cases, we discovered that lower-field stimuli activated regions in the lower bank of the fissure, which is contrary to what the classical model predicts.

Our experiments were conducted in a magnetically shielded chamber to eliminate background “noise” from external magnetic fields. The weak magnetic fields from the brain were recorded with a seven-sensor, SQUID-coupled (**S**uperconducting **QU**antum **I**nterference **D**evice) gradiometer system while subjects viewed small circular stimuli, which were presented one at a time to different positions in the lower right visual field (parallel with the horizontal and vertical meridians). Multiple-dipole, spatio-temporal models—using a Nelder-Meade simplex search algorithm and spherical or realistic head models based on MRI data—were applied at various intervals of time (80 to 120 ms, 80 to 150 ms, 80 to 165 ms, etc.). Model adequacy was assessed by examining the resulting reduced chi-square (χ_r^2) values at each point in time and the overall χ_r^2 for spatio-temporal fits. Errors in parameter estimation resulting from noise were assessed by Monte Carlo analyses.

Three to five sources were identified for each subject during the initial 80- to 165-ms poststimulus interval. Figure 1 displays sample empirical and theoretical field distributions for one subject when the stimulus was

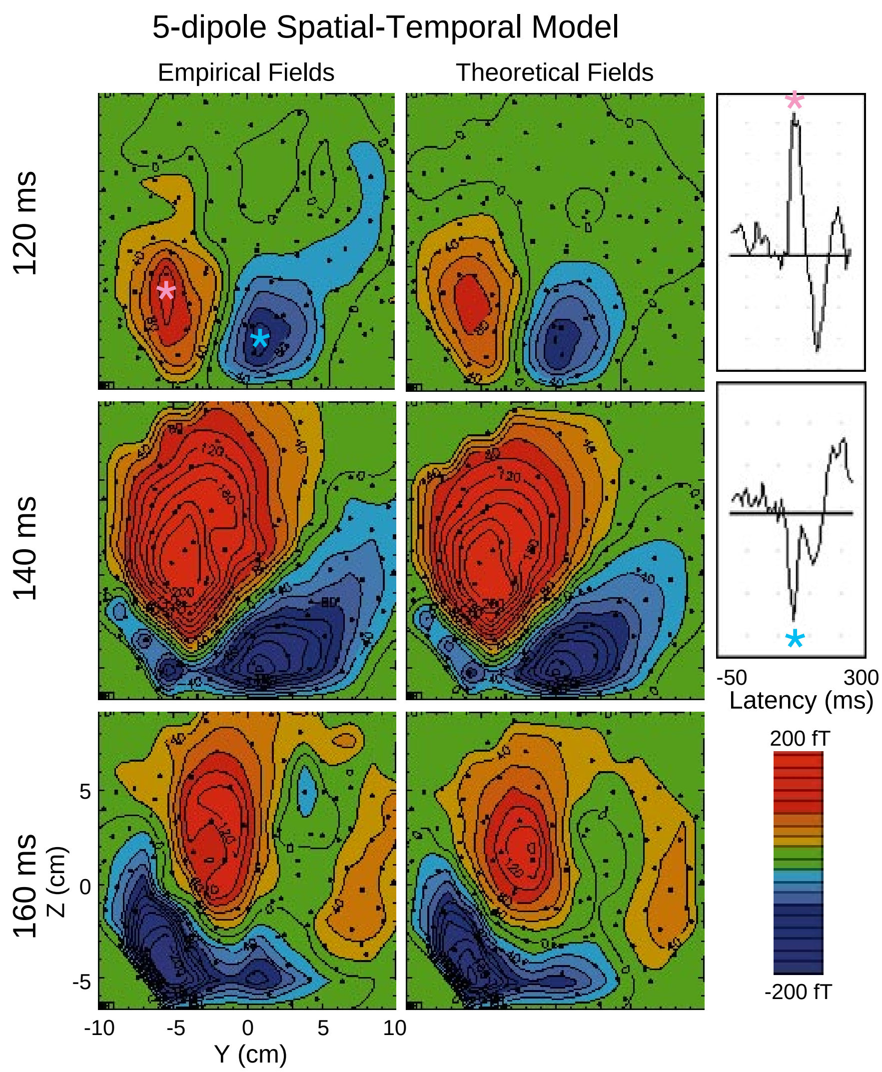


Fig. 1. Empirical and five-dipole theoretical field distributions (i.e., left and right columns, respectively) are shown for one stimulus location at 20-ms intervals. These surface projections are on a plane; Y = 0 represents the midline on the back of the head. Positive fields (i.e., flux emerging from the head) are shown in red, and negative fields (i.e., re-entering flux) are shown in blue. The black dots represent the sensor locations. Sample magnetoencephalography (MEG) waveforms are displayed in the upper right portion of the figure. The red and blue asterisks reflect peaks in the waveforms at 120 ms. These waveforms were acquired from sensors in the vicinity of the field extrema shown by the asterisks on the empirical field distributions at 120 ms. The waveforms represent an average of 100 individual neural responses to a stimulus. A 500-ms prestimulus baseline was acquired; only 50 ms of the prestimulus baseline is shown in the figure. The color bar shown in the lower right portion of the figure indicates the strength of the extrema in the field distributions.

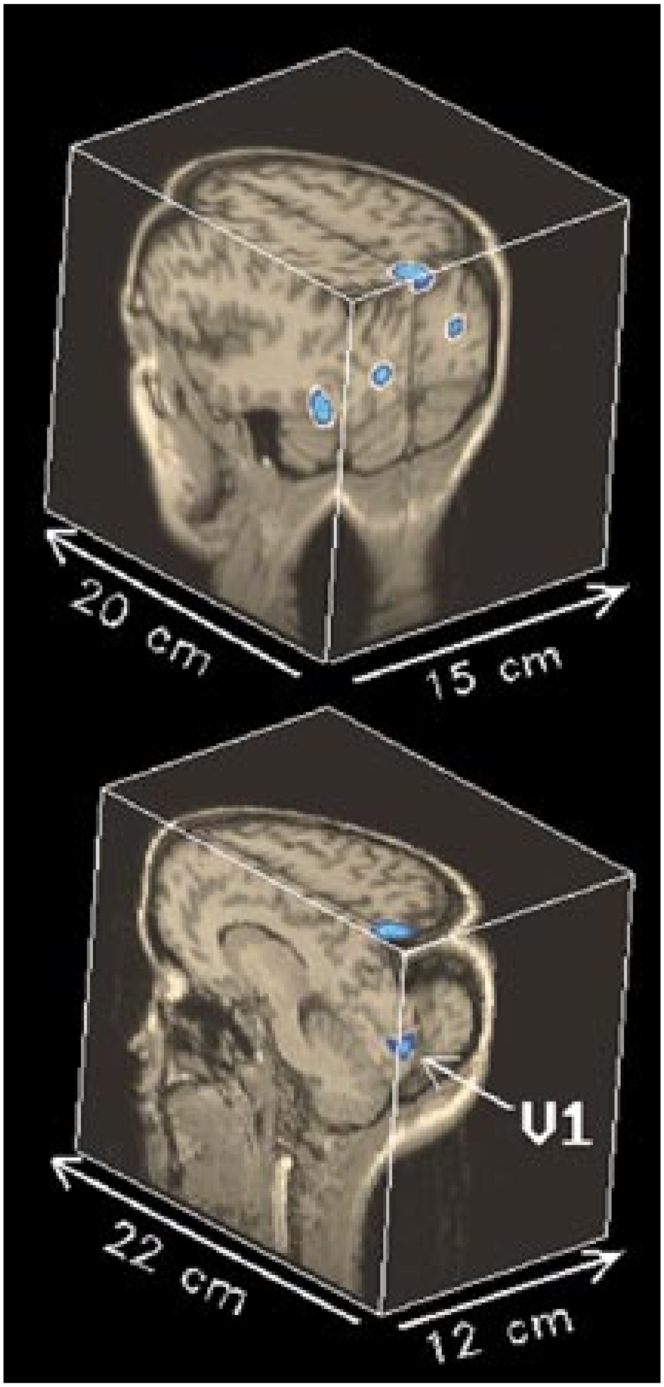


Fig. 2. Source locations from the best-fitting five-dipole model (80 to 165 ms) are located on a three-dimensional MRI volume model for this subject. The left hemisphere is displayed on the left side in the figure. Magnetic resonance images were acquired volumetrically on a 1.5-T Siemens imager at the New Mexico Regional Federal Medical Center. MRIVIEW, an imaging software program developed by D. M. Ranken and J. S. George of P-21, was used for integrating functional and anatomical information. The MRI coordinate system was reconciled with the MEG head-centered coordinate system by identifying a set of anatomical reference markers (e.g., nasion and periauricula) on the three-dimensional surface renderings of the head.

presented to the most central position in the lower right visual field. The theoretical fields were obtained from the best-fitting, five-dipole, spatio-temporal model (80 to 165 ms). Sample neuromagnetic waveforms are also shown in the upper right portion of Fig. 1.

Figure 2 shows volume histograms of source location estimates from 100 Monte Carlo trials (displayed in blue) on three-dimensional reconstructed images of a subject's brain. Four of the five regions active in response to the stimulus are evident in the three-dimensional image in the top panel. The V1 source is shown in the midsagittal view in the bottom panel. These regions are consistent with our results from other studies.

Once the multiple-dipole models were derived for each stimulus condition, we examined V1 retinotopy by comparing anatomical locations for the best-fitting V1 sources across the seven stimulus locations. Figure 3 displays V1 sources evoked by the seven stimuli. Note the systematic relationship between the location of each stimulus in the visual field (upper left inset) and the source locations around the fissure. Two separate paths of V1 sources, representing placements near the vertical and horizontal meridians, can be seen in Fig. 3 (see connected dots). As predicted from the classical model, V1 sources for stimuli positioned in parallel with the vertical meridian were more anterior for the peripheral stimulus placements (*e.g.*, the source evoked by the stimulus depicted in red was posterior to the sources evoked by the stimuli depicted in blue and green). However, source locations for stimuli positioned in parallel with the horizontal meridian (*i.e.*, red, orange, yellow, and green) were not located along the lateral extent or base of the calcarine fissure, nor was there a systematic shift in source location in the anterior direction (as a function of eccentricity) as predicted by the classical model. These data suggest that the representation of the horizontal meridian for this subject is canted downward relative to the fissure in a posterior-anterior direction. Data from other subjects also suggest a similar departure from the classical model for that portion of the V1 retinotopic map corresponding to the horizontal meridian. Taken together, these data suggest that lower-field stimuli may activate regions in the lower bank of the fissure when peripheral stimuli are located near the horizontal meridian.

The evidence for variability in the shape and location of calcarine fissures and in the way V1 maps onto the fissure as reported here is consistent with human anatomical studies. Area V1 is the only visual area that can be identified anatomically because of the

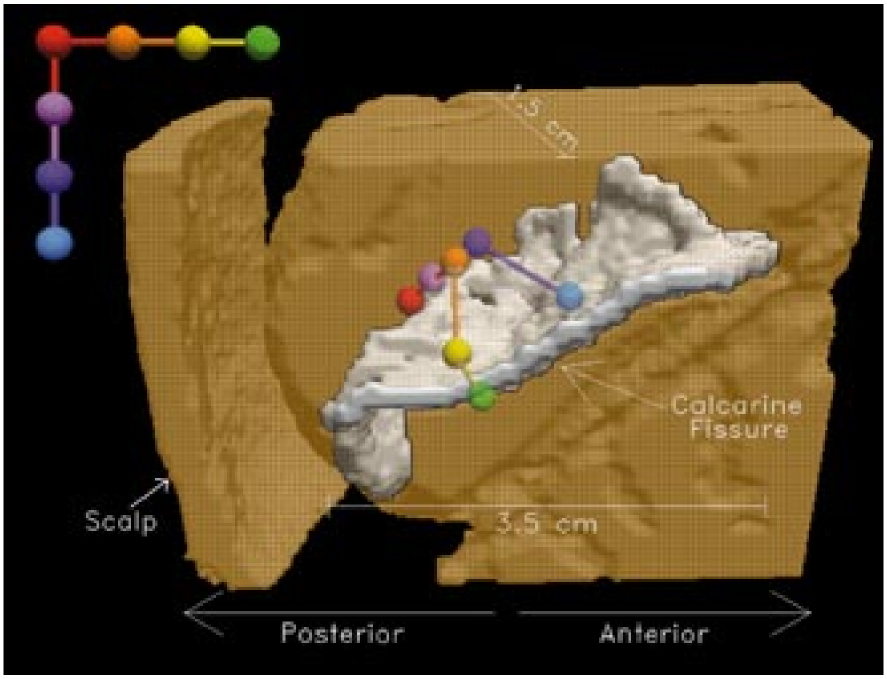


Fig. 3. The calcarine fissure (white) can be seen projecting into the depths of the left occipital lobe (~1.5 cm) from this midsagittal view. This three-dimensional image of the calcarine was obtained by outlining the fissure (in white) in a series of contiguous MRI slices. The V1 source locations, evoked by the seven stimuli and modeled from 80 to 120 ms, are displayed relative to the fissure. The locations of each stimulus in the lower right visual field are shown in the inset displayed in the upper left corner of the figure. The left outermost region of the three-dimensional image (i.e., the detached section) represents the scalp at the posterior region of the head. A portion of the cerebellum is seen at the bottom of the figure.

"stria of genari," a band of myelin that runs through the extent of this region. In some cases, V1 has been reported to be completely displaced onto the upper bank of the calcarine fissure, or it may be located entirely on the lower bank of the fissure. These cases are extreme, but cases where V1 symmetrically lines both lower and upper banks of the fissure (as suggested by the classical model) are also rare occurrences.

The results of our experiments indicate that a direct and comprehensive examination of retinotopic organization in human visual cortex can be obtained from neuromagnetic measures coupled with appropriate modeling procedures and anatomical MRI. These data, obtained *in vivo* from noninvasive measurement techniques, represent the most detailed demonstration of human V1 retinotopy to date.

Magnetized Target Fusion

J. S. Shlachter, B. G. Anderson, J. W. Canada, P. Rodriguez, R. C. Smith, L. R. Veeser, G. Idzorek, D. W. Scudder, O. F. Garcia, L. J. Tabaka (P-22), I. R. Lindemuth, P. T. Sheehey (X-1), R. E. Reinovsky (DX-DO), J. M. Christian, C. E. Findley, J. H. Goforth, H. Oona (DX-15), R. C. Haight, N. S. P. King, G. L. Morgan (P-23), R. E. Chrien (P-24), S. M. Younger (CISA), C. A. Ekdahl, Jr. (PDNW), R. Kirkpatrick (NIS-9), G. L. Stradling (PDDoD), B. J. Warthen (EG&G Energy Measurements, Inc.), V. Chernyshev, V. Mokhov, N. Bidylo, A. Buyko, A. Demin, V. Dolin, B. Egorychev, S. Garanin, V. Ivanov, V. Korchagin, O. Mikhailov, I. Morozov, S. Pak, E. Pavlovskii, N. Seleznev, A. Skobelev, G. Volkov, V. Yakubov (All-Russian Scientific Research Institute of Experimental Physics, Arzamas-16, Russia)

Magnetized Target Fusion Overview

For several decades, researchers worldwide have been investigating methods of controlling thermonuclear reactions in the quest for a fusion energy source. These studies have focused primarily on two independent concepts: magnetic confinement and inertial confinement of a hot plasma. In magnetic fusion, various topologies of magnetic fields have been used to confine the plasma and prevent it from cooling off through contact with the relatively cold container wall. The time required for confinement in the most advanced geometry used to date, the tokamak, is on the order of seconds, and the plasma density is several orders of magnitude below atmospheric values. In inertial-confinement fusion, the plasma is held together by its inertia, and the experiments are conducted in a few billionths of a second—a time too short for the plasma to explode. The plasma density for this concept exceeds that of a solid. Magnetic and inertial confinement thus differ from each other by several orders of magnitude in key parameters, yet both are projected to cost several billion dollars and require many years of development.

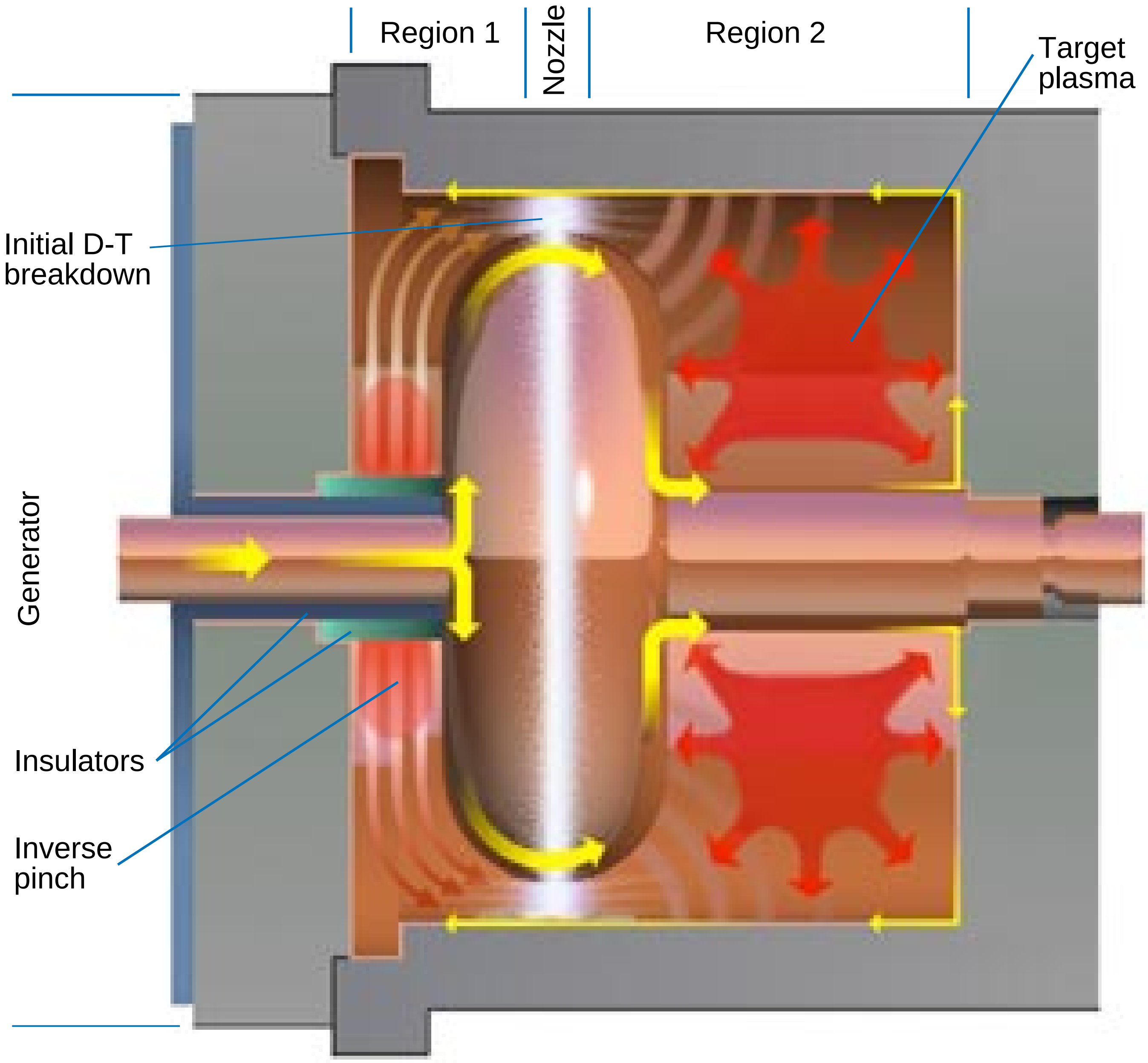
Magnetized target fusion (MTF) is an approach to fusion that uses a magnetic field in the plasma to reduce the heat losses from thermal conduction and to trap the alpha particles from the fusion reactions. Ideally, the cost, complexity, and development time for MTF offer a significant improvement over both inertial- and magnetic-confinement schemes. In MTF, the magnetic field does not confine the plasma. In fact, the plasma is confined by the walls of a solid chamber. Following the formation of the "magnetized target plasma," the chamber is imploded. This process performs work on the plasma, adiabatically heating it to ignition conditions. MTF is in some sense a slow inertial-confinement concept; the magnetic field reduces the thermal conduction and allows the implosion to proceed in millionths rather than billionths of a second. More efficient and energetic implosion drivers and larger and more manageable targets can thus be used.

Any specific MTF concept consists of a formation scheme for the magnetized target and an implosion driver system. A collaboration developed over the past few years between researchers at Los Alamos and at the premier Russian nuclear weapons laboratory (VNIIEF) located at Arzamas-16 has examined both pieces of this problem independently in an historic program that involved experiments performed at both institutions. The leading target-formation scheme examined is known by the Russian acronym MAGO. Los Alamos scientists have participated actively in three MAGO experiments to date. MAGO I was performed in April 1994 at Arzamas-16, whereas MAGO IIP and MAGO II were conducted in October 1994 in Los Alamos.

The MAGO Concept

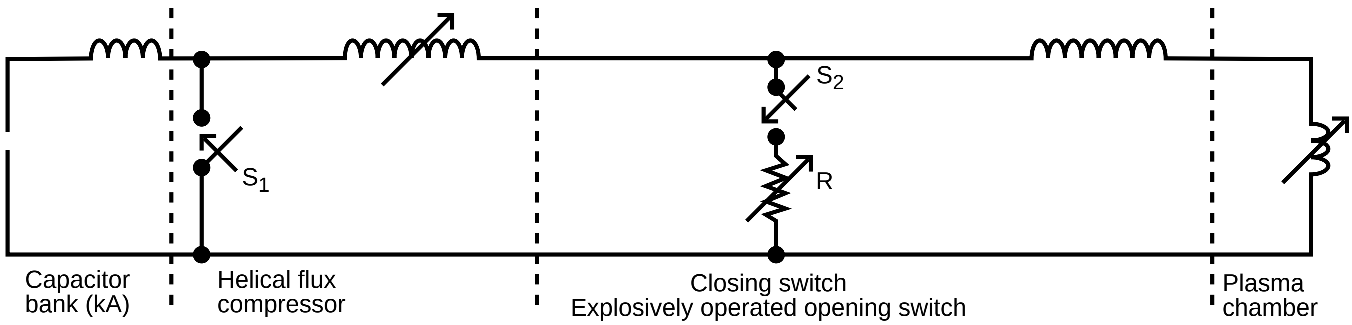
Our MAGO experiments begin with a static gas fill of a mixture of deuterium and tritium at a pressure of approximately one-seventieth of an atmosphere in a 20-cm-diam copper chamber (Fig. 1). The chamber is attached to the end of an explosive pulsed-power generator, which is used to create the insulating magnetic field and to form the plasma. No implosion of the chamber was attempted in these experiments because

Fig. 1. Artist's rendition of the dynamic processes that occur in the MAGO target chamber.



the goal was only to study the formation and characteristics of the target plasma. In Stage I, switch S_2 is open (Fig. 2), forcing current to flow through the chamber, and the generator produces a current of 2 MA in a few hundred millionths of a second. The magnetic field that is created as the current flows through the chamber will reduce heat losses once the plasma is created, but the relatively slow rate at which the current rises ensures that no electrical breakdown in the deuterium-tritium gas mixture occurs during this stage. Through a complicated explosive switching system, the chamber is then temporarily disconnected from the generator. The chamber current maintains the insulating magnetic field produced in Stage I while the generator current continues to rise to about

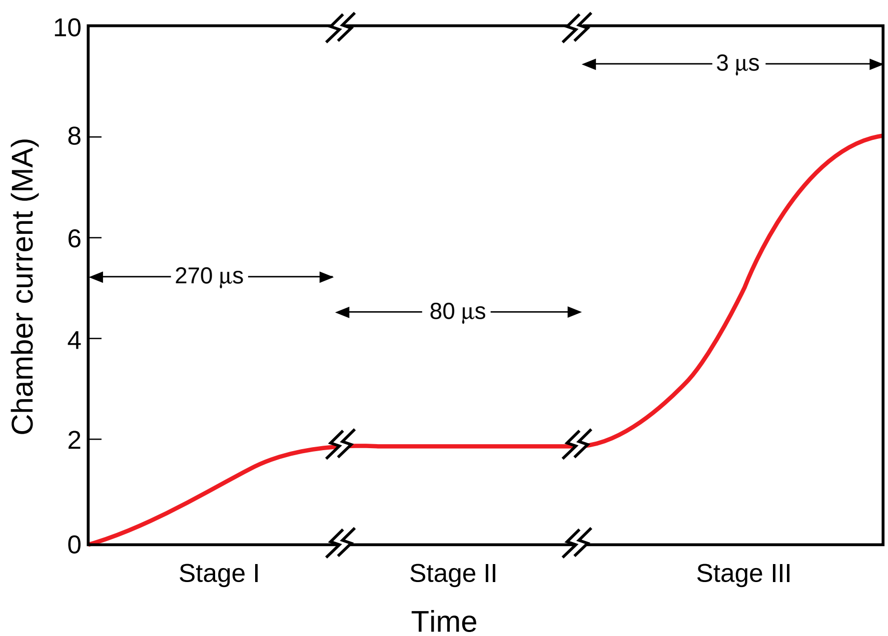
Fig. 2. Electrical schematic of the explosive pulsed-power generator and the plasma load.



8 MA during Stage II. Additional explosive switching then reconnects the chamber to the generator in Stage III (see switch "R" in Fig. 2), and the rapid rise in current causes a breakdown of the gas within the chamber, creating a plasma (Fig. 3).

Calculations of the dynamic process in Stage III, performed in X Division, suggest that the breakdown of the gas mixture first occurs in the "nozzle" region (*i.e.*, the silver illuminated region in Fig. 1 surrounding the center electrode). This breakdown produces a weak ionizing shock wave that creates some plasma in region 2 of the MAGO chamber. According to calculations, this process is followed by a breakdown of the gas mixture in region 1. The subsequent plasma that is formed is magnetically driven around the center electrode, swept into the

Fig. 3. Current rise associated with Stages I, II, and III.



"nozzle" region, and then accelerated into the shock-wave-produced plasma of region 2. A burst of neutrons is produced via the stagnation of the accelerated plasma in region 2, and a relatively quiescent, warm, dense plasma is then formed. This plasma leans against the walls in region 2 but is also insulated from these walls by the magnetic field produced during Stage I. Ideally, the MAGO chamber geometry creates a magnetized target suitable for imploding and heating to thermonuclear conditions.

The explosive pulsed-power system used to form the MAGO plasma does not appear to be the appropriate system for driving the implosion. Raising the temperature of the plasma to thermonuclear values will require a driver system with hundreds of megajoules of energy. Our colleagues at VNIIEF have developed a novel high-explosive generator, which is both energetic and modular and is designed in a disk geometry. The first collaborative experiment between VNIIEF and Los Alamos performed in Arzamas-16 in September 1993 was in fact a liner implosion test performed with a disk-explosive magnetic generator—possibly a small-scale version of the driver that might be used to implode the MAGO plasma. Performing a "full-up" MTF experiment using MAGO is perhaps premature at this time because whether a suitable target plasma has been produced in our experiments remains unclear.

Future Plans

The diagnostics for the three MAGO shots performed to date have been focused on understanding the plasma-formation mechanism and on determining the level of impurities associated with material mixing into the plasma from the walls and insulator. Experimentalists in P and DX Divisions have examined the plasma density, the neutron production, and the emitted radiation (both in the visible and x-ray portions of the spectrum) to learn how MAGO works. Although we do not yet have definitive measurements to confirm that the target plasma is sufficiently hot and dense to warrant implosion, a consistent picture that suggests that MAGO may be a logical approach to magnetized target fusion is emerging. Future experiments will further test our picture of the MAGO concept and may lead to a near-term test of MTF with an imploded target plasma.

Atlas Project

W. M. Parsons (P-22)

Introduction

The Atlas project within the aboveground experiments (AGEX II) program at Los Alamos is an element of a strategic response to the changing requirements being placed on Department of Energy (DOE) defense programs. These requirements include the Presidential call to ensure the safety and reliability of U.S. nuclear weapons without underground nuclear testing. DOE and the national laboratories will continue their responsibility for maintenance, surety, and reliability of the nation's remaining stockpile. This stockpile stewardship has been identified as a key strategic focus area within DOE and national security strategic planning. "Aboveground experiments," or AGEX (*i.e.*, experiments without a nuclear explosion), have been identified as an important part of the DOE's strategy to maintain the expertise and capability necessary for this stewardship.

High energy density AGEXs (often called AGEX II) that are appropriate to the physics of thermonuclear secondaries and some primary issues require three distinct environments to successfully support the necessary weapons-related experiments. These three classes of capability include pulsed-power, high-energy lasers, and ultrahigh-intensity lasers. Both the pulsed-power and laser capabilities are called out in the DOE Defense Programs Stockpile Stewardship Plan.

Two significant pulsed-power capabilities currently exist at Los Alamos: the Pegasus II 4.3-MJ capacitor bank and the Procyon high-explosive-driven, pulsed-power generator. These capabilities use an optimized and cost-effective technological approach with microsecond-long pulses for AGEX weapons physics. Pegasus and Procyon are presently capable of performing some weapons-relevant experiments; however, additional energy is required to reach conditions needed to examine some specific issues. Providing this capability requires the construction of the Atlas 36-MJ Capacitor Bank Facility at Los Alamos and the related modifications to existing buildings. Atlas will become the principal experimental pulsed-power resource for AGEX II.

Table 1 shows a comparison of baseline parameters and experimental capabilities for Pegasus II and Atlas. The entries in the last two rows of the table reflect the use of a plasma "switch" as part of the experimental configuration for power compression from 2 to 3 µs to <0.5 µs. The use of this switch in the configuration provides the maximum target temperatures for radiation applications. This switch is not used or required for the hydrodynamics tests and other experiments, and radiation experiments may be performed without it at somewhat derated parameters.

Atlas will also become a useful tool for basic research. The facility will be capable of subjecting ~cm^3 volumes of a sample material to pressures exceeding 20 Mbar and of producing magnetic fields in excess of 1,000 T. These features will allow experimentalists useful opportunities to explore the physics of matter under these extreme conditions.

Table 1
Comparison of Baseline Parameters and Experimental Capabilities

Baseline parameters	Pegasus II	Altas
Current to target	12 MA	20 to 25 MA
Direct-drive pulse length	6 µs	2 to 3 µs
Stored energy	4.3 MJ	36 MJ
Capacitance	864 µf	200 µf
Output voltage (90% charge)	90 kV	540 kV
Inductance (nominal)	30 nH	30 nH

Experimental capabilities

Quasi static (adiabatic compression)		
Volume > 1 Mbar	2 cm^3	12 cm^3
Volume > 10 Mbar	(n/a)	1 cm^3
Volume > 1 MG	40 cm^3	250 cm^3

Dynamic (implosion)

Implosion kinetic energy, maximum	0.5 MJ	> 3 MJ
Soft x-ray output (with switch)	0.2 MJ	3 to 4 MJ
Peak temperature (with switch)	~100 eV	130 to 200 eV

Requirements

The Atlas machine must be flexible to accommodate a wide variety of weapons-physics and basic-research experiments. The majority of these experiments will be studies of radiation and hydrodynamic phenomena. The Atlas machine must meet certain requirements to produce the types of conditions required for these experiments. It must be able to produce a peak current of 20 to 25 MA with a rise time between 2 to 3 µs. The radial and axial diagnostic access around the target chamber must be maximized. The machine must be reliable and designed to perform experiments twice weekly with a lifetime of at least 10 years. Finally, the facility should include full support services for users, including data analysis, film processing, and planning and coordination areas. An artist's conception of the Atlas facility is shown in Fig. 1.

System Description

The Atlas system has three major, high-energy subsystems: the capacitor bank, the target chamber, and the capacitor-bank charging system.

Capacitor bank. The Atlas 36-MJ capacitor bank will be constructed of twenty 1.8-MJ Marx modules. In the present design, each module has 10 stages, which are each precharged to 60 kV. When the railgap switches on the front of each module are triggered, the individual stages are connected in series and the Marx-module voltages add to 600 kV. Flat-plate resistors on the rear of each module form the rest of the series circuit. These resistors limit potential fault currents and prevent voltage reversal on the capacitors. Figure 2 illustrates the construction of a single Marx module.

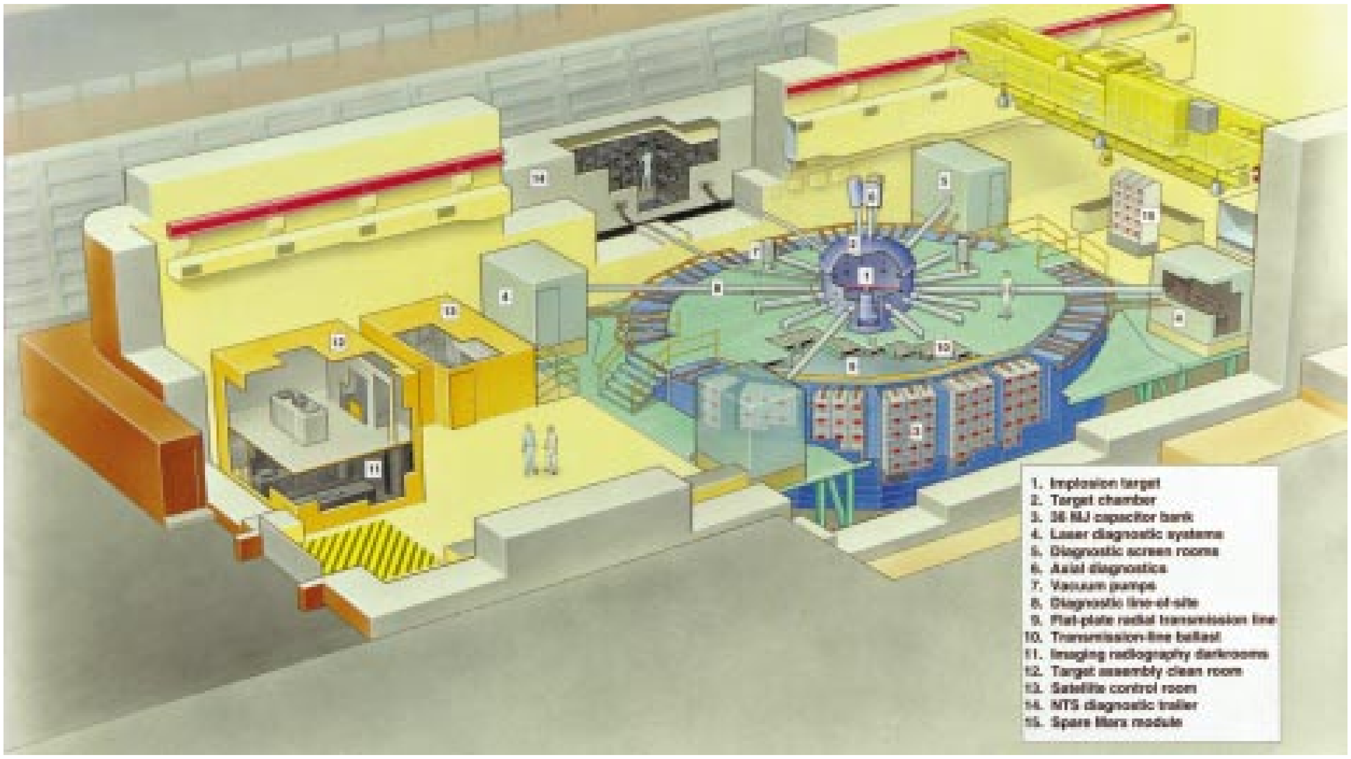


Fig. 1. Artist's conception of the Atlas Facility.

When the 20, parallel-connected Marx modules are simultaneously discharged, current flows through a disc-type transmission line into a centrally located load or liner. Near the load, the current density and associated magnetic fields dramatically increase. The interaction of the current and magnetic field produce Lorentz forces that implode a cylindrical liner located in the target chamber. A lightweight liner can collide with itself on axis, converting its kinetic energy into soft x-rays. A heavier liner can be used to either compress sample materials to high pressures or, when driven into a central target, produce extremely high shock pressures.

Target chamber. The target chamber will have walls that are sufficiently far from the target for the chamber to survive intact from the shrapnel and debris of the discharge. This requirement is mandated to achieve the maximum anticipated shot rate of 100 per year. The approximate overall dimensions of a chamber meeting these requirements is 10 ft in diameter. Present estimates indicate more than 12 MJ will be trapped and dissipated in the target chamber when the vacuum insulator crowbars at the time the Poynting vector changes direction. The anticipated experiments require a high degree of flexible diagnostic access. Diagnostic access for end-on views of the target will be available. Radial access in the target plane is critical. Several in-line port pairs for diagnostics that involve active backlighting with visible light or x-rays will be available. The large chamber dimensions necessitate re-entrant port capability for those diagnostics that require high flux. The target chamber will also contain an internal platform structure for personnel involved with diagnostic alignment.

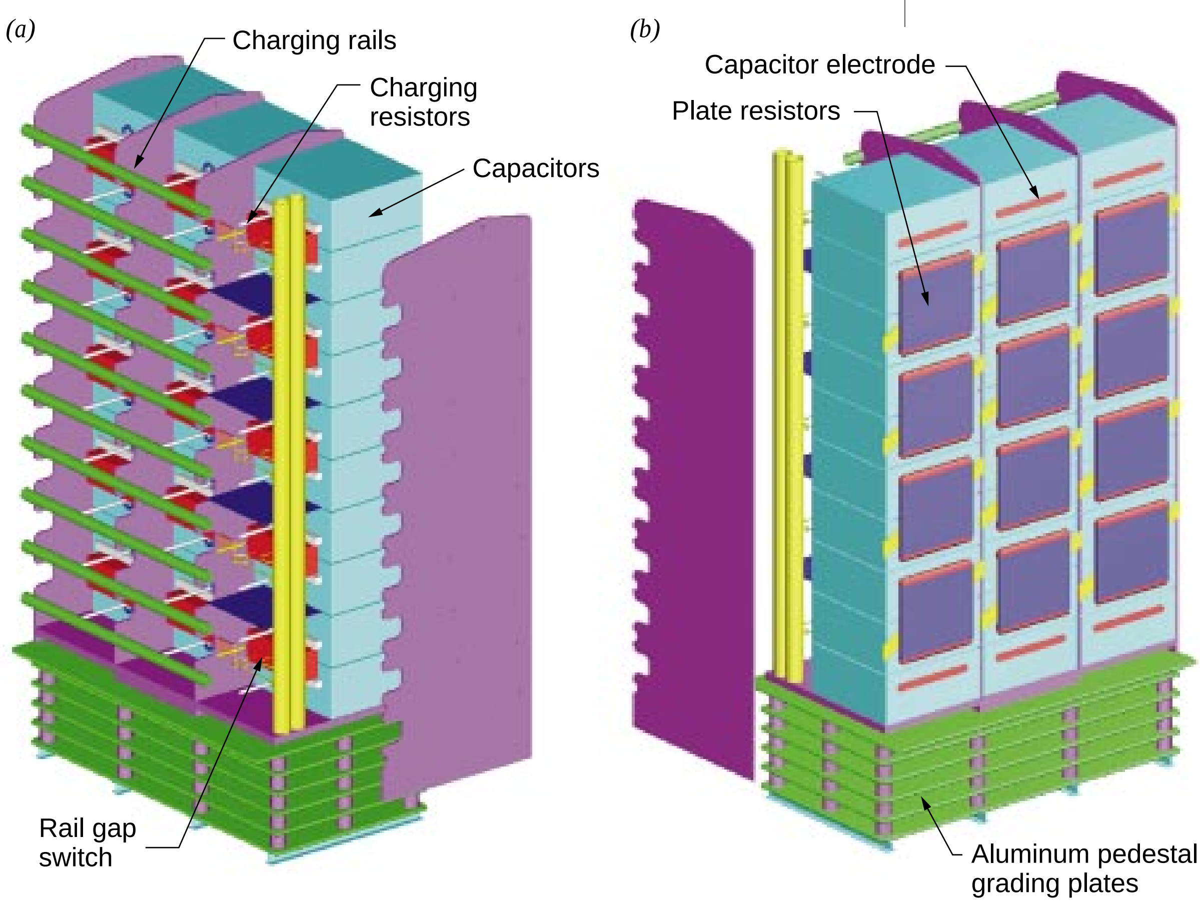
Charging system. The railgap switch was developed by Maxwell Laboratories and is extensively used in the Shiva Star Facility (144 units). Atlas will use 300 of these switches. Because an inadvertent prefire of a railgap switch is the most likely failure mode in the system, reliable operation of the railgaps is critical for Atlas to achieve a system failure rate of less than 5%. Based on the assumption that prefire probability is proportional to the time a switch has to hold off voltage, a research and development program has been initiated to measure railgap prefire rates as a function of capacitor charging time. Conventional charging techniques can be used to charge the Atlas capacitor bank in the 6- to 60-s range. If faster charging is required to prevent prefire, an inductive storage and transfer system will be used.

The inductive storage and transfer system has been conceptually designed and will be capable of charging the Atlas capacitor bank in 40 ms. Several electrical stages will be used to obtain time-energy compression. Line power will be used to spin a nearby 1,430-MVA motor-generator to 1,800 rpm in approximately 20 minutes. The motor-generator will then be switched to an 80-MVA alternating current to direct current converter, which will charge a 50-MJ inductor to 28 kA in 5 s. When the inductor is switched into the capacitor bank, it will charge the bank to 60 kV in 40 ms. Triggering the railgap switches immediately will then minimize their voltage hold-off time and the probability of a spurious prefire.

Cost and Schedule

Atlas has been proposed as a $43 million line-item construction project. An additional $5 million in other project costs, including the ongoing research and development effort, will be required to successfully complete the project. The formal design and construction efforts will take four years to complete with an anticipated start in early FY 96.

Fig. 2. Atlas Marx module: (a) front view and (b) rear view.



The Russian-American Gallium Experiment (SAGE) and the Solar-Neutrino Problem

T. J. Bowles (P-23)

Perhaps the most outstanding discrepancy between prediction and measurements in current particle physics comes from the classical "solar-neutrino problem," whereby a large deficit of high-energy ^{8}B solar neutrinos is observed. The discrepancy between the solar-neutrino capture rate predicted by calculations of the standard solar model (SSM) and by the ^{37}Ar rate measured in a chlorine experiment has persisted for more than twenty years. This deficit has been verified by the Kamiokande water-Cerenkov experiment, which observes only about one-half of the ^{8}B flux predicted by the SSMs.

The ^{37}Cl and Kamiokande experiments are primarily sensitive to the high-energy ^{8}B solar neutrinos, whose production rate depends critically ($\propto T_c^{18}$) on the core temperature of the Sun. One means to force agreement between the predictions and experiment is to incorporate possible new phenomena to reduce the core temperature, thereby reducing the predicted fluxes. Reducing the ^{8}B flux by a factor of 2 to 3 only requires a reduction of the central temperature of the Sun by 5 to 6%. The numerous nonstandard solar models (NSM) proffered incorporate a variety of heavy-element abundances, high magnetic fields, turbulent diffusion, continuous mixing, rapid rotation, convective mixing of hydrogen into the core, new equations of state, and other effects. However, not one of the NSMs has been able to reproduce the observed ^{8}B flux without running into problems with reproducing other measured physical properties of the Sun. Yet one cannot rule out the possibility that there may be some additional physics (*i.e.*, not included in the SSMs) that will resolve the problem.

Another possible means of reducing the observed solar-neutrino flux is to invoke new particle physics, which either reduces the production rate of solar neutrinos or causes the neutrinos to "disappear" during their transit to Earth. A plethora of possible extensions of the standard electroweak model has been presented whereby the neutrinos naturally acquire a mass and lepton number is no longer strictly conserved. One of the implications of this extension is that the flux of neutrinos produced in the Sun may be accurately predicted by the SSMs, but the flux of electron-type neutrinos measured by solar-neutrino detectors from Earth may be depleted because of oscillations. Solar-neutrino detectors are sensitive only to electron-type neutrinos and thus would not be sensitive to other types of neutrinos that are produced in neutrino oscillations.

Other mechanisms involving new physics have also been suggested to account for the observed deficit of solar neutrinos. Rather than changing the properties of the neutrinos, some of these hypotheses involve lowering the core temperature of the Sun, such as by weakly interacting massive particles, or WIMPs. But all these other mechanisms have been effectively ruled out by either laboratory measurements or astrophysical observations. Thus, it appears that the only viable candidate for new physics as the explanation of the solar-neutrino problem is that involving neutrino oscillations.

Analyses of the consistency of the chlorine and Kamiokande II data conclude that the results are highly inconsistent with any astrophysical

Fig 1. The SAGE deep underground laboratory at the Baksan Neutrino Observatory in southern Russia. Shown is the control room at the left, the chemical reactors (green vessels in the center with red drive motors on top) holding the gallium, and the chemical extraction aparatus on the right.

explanations and are better described by Mikheyev-Smirnov-Wolfenstein (MSW) neutrino oscillations in which the solar neutrinos undergo a resonant oscillation from the electron-type neutrino produced in solar fusion reactions to another neutrino type. Two things must be noted about MSW oscillations: (1) the probability for matter to oscillate depends on the neutrino energy and therefore can result in a distortion of the energy spectrum from that predicted by the SSMs, and (2) one finds that the solar-neutrino experiments have sensitivities to much smaller oscillation probabilities resulting from the MSW resonant amplification. Although MSW neutrino oscillations would appear to offer a valid solution to the classical solar-neutrino problem, one cannot rule out an astrophysical origin of the classical “solar-neutrino problem.”

Resolving the origin of the solar-neutrino problem requires a measurement of the flux of the p-p neutrinos created by the dominant energy-producing mechanism in the Sun. The $^{71}Ga(\nu_e, e^-)^{71}Ge$ reaction provides the only feasible means at present to measure low-energy solar neutrinos. The flux of p-p neutrinos is directly tied to the measured luminosity of the Sun in an essentially model-independent manner. If a significant deficit of p-p neutrinos were to be observed, then a nonastrophysical solution to the solar-neutrino problem would be required.

The two gallium experiments (SAGE and GALLEX) both observe the reaction $^{71}Ga(\nu_e,e^-)^{71}Ge$ produced by solar neutrinos by chemically extracting and observing the subsequent decay of the ^{71}Ge atoms. The threshold for this reaction is 233 keV so that the gallium experiments are sensitive to all of the neutrino-producing reactions in the Sun. In particular, 54% of the total rate predicted by the SSM is due to the p-p neutrinos. Thus, the prospect exists that the gallium experiments may be able to unravel solar-physics effects from particle-physics effects because the flux of p-p neutrinos is essentially independent of solar modeling.

SAGE, the Russian-American gallium experiment, uses the gallium-germanium neutrino telescope situated in an underground laboratory specially built at the Baksan Neutrino Observatory of the Institute for Nuclear Research of the Russian Academy of Sciences in the Northern Caucasus Mountains. The telescope is located under Mount Andyrchi and has an overhead shielding of about 4,700 ft of rock.

SAGE initially used 30 tons of gallium but now uses 57 tons of gallium in the form of the liquid metal. The individual ^{71}Ge atoms (produced by inverse beta decay on ^{71}Ga) and about 700 µg of natural germanium (added as a carrier to measure the extraction efficiencies) are chemically extracted, purified, and synthesized into germane (GeH_4). A measured quantity of xenon is then added, and this mixture is inserted into a sealed proportional counter. The SSM predicts a production rate of 1.2 ^{71}Ge atoms per day in 30 tons of gallium. Taking into account all efficiencies, SAGE should detect only about four ^{71}Ge atoms from 30 tons of gallium in each run—that is, assuming the SSM flux. Thus, the counting backgrounds must be kept to a small fraction of a count per day.

^{71}Ge decays with an 11.4-day half-life by electron capture to the ground state of ^{71}Ga. The only way to observe this decay is to detect the low-energy K and L peaks from Auger electrons and x-rays produced during electron-shell relaxation in the resulting ^{71}Ga atom. The low-energy electrons and x-rays are detected in a small-volume proportional counter. The proportional counter is placed in the well of an NaI detector (used as a veto) inside a large passive shield and counted for 3 to 6 months. Pulse-shape discrimination based on rise-time measurements is used to separate the ^{71}Ge decays from background. The data-analysis procedure selects events that have no NaI activity in coincidence within the ^{71}Ge K-peak acceptance window. A maximum likelihood analysis is then carried out on these events by fitting the time distribution to an 11.4-day half-life exponential decay plus a constant rate background. Only the K peak has been used to date in the analysis presented by SAGE because of the considerably higher backgrounds in the L peak.

Initially, a low signal was picked up in the first data run with an upper limit of 60% (*i.e.*, 90% confidence level) of the SSM prediction. Thus, a great deal of effort was expended to check that the experiment was working correctly. A series of tests indicated that the experiment was operating with very close to 100% efficiency. These tests included placing a known number of ^{71}Ge atoms in 7 tons of gallium and extracting them. Next, the ^{70}Ge and ^{72}Ge were produced *in situ* using (n,γ) reactions on gallium, and the germanium was extracted.

Following these tests, SAGE was upgraded from 30 tons to 57 tons, and the counting system was improved so that both the K and L peaks could be observed. Additional data have been taken through December 1994, and the present SAGE result, which is still based only on analysis of the K peak where backgrounds are lower, is that SAGE observes only 52 ± 8 +4/-5% of the SSM prediction. This result coincides with the observation of only the p-p neutrinos and the absence of ^{7}Be and ^{8}B neutrinos. The results from GALLEX are in agreement with SAGE and thus also support this observation.

The fact that SAGE apparently does not observe the ^{7}Be neutrinos (which occur at energies lower than the ^{8}B neutrinos but higher than the p-p neutrinos) is perhaps the strongest evidence that neutrinos must be oscillating. The crux of the problem is that Kamiokande directly observes ^{8}B neutrinos, which means that ^{7}Be must be present in the Sun as ^{8}B is produced by the ^7Be (p,γ) reaction. However, SAGE does not observe any measurable ^7Be flux, which coincides with the apparent lack of any ^7Be flux detected in the chlorine experiment. Thus, apparently ^7Be is present in the Sun, but there is no evidence of ^7Be neutrinos, which makes it very difficult to invoke any astrophysical explanation of the solar-neutrino problem. However, the results of all four solar-neutrino experiments are consistent with MSW neutrino oscillations in which the energy dependence of the oscillations would result in no suppression of the p-p neutrinos, almost complete suppression of the ^7Be neutrinos, and a factor of 2 suppression of the ^8B neutrinos.

To more fully test the operation of the SAGE detector, we are carrying out an experiment using an artificial neutrino source. A suitable neutrino calibration source can be made using ^{51}Cr, which decays with a 27.7-day half-life by electron capture and subsequently emits monoenergetic neutrinos. We have produced a 0.5-MCi ^{51}Cr source, which should produce a few hundred atoms of ^{71}Ge in 13 tons of gallium. Preliminary results from this experiment indicate that everything is operating as expected. However, several more months of data collection are required to obtain an accurate measurement of the detector operation.

Thus, the data from SAGE, together with the results from the other solar-neutrino experiments, indicate that possible evidence for neutrino oscillations is observed in the solar-neutrino experiments. Various analyses indicate it is unlikely that changes to the SSMs can accommodate the results. The most likely consistent explanation is that we are observing matter-enhanced MSW neutrino oscillations. Yet a number of researchers state that it is still not possible to completely rule out an astrophysical explanation of the observed deficits. A new generation of detectors [see A. Hime *et al.*, “The Solar Neutrino Puzzle,” Physics Division Progress Report, January 1, 1994–December 31, 1994, p. 54, for information on the Sudbury Neutrino Observatory (SNO)] will provide model-independent tests of the origin of the solar-neutrino problem. Thus, we believe that the SAGE and SNO experiments will provide crucial evidence for the resolution of the solar-neutrino problem.

High-Energy Neutron Radiography at the Weapons Neutron Research Facility

A. Gavron, A. Bridge, W. P. Abfalterer, S. J. Seestrom, J. L. Ullmann, N. S. P. King, G. L. Morgan (P-23), C. L. Morris, M. M. Murray, D. M. Lee, J. D. Zumbro (P-25), F. Dietrich, T. Wenaus (Lawrence Livermore National Laboratory)

A Los Alamos National Laboratory and Lawrence Livermore National Laboratory collaboration has implemented an experiment designed to test some basic concepts of neutron radiography using the high-energy neutron beam at the Weapons Neutron Research (WNR) Facility. The results of the experiment are presented here.

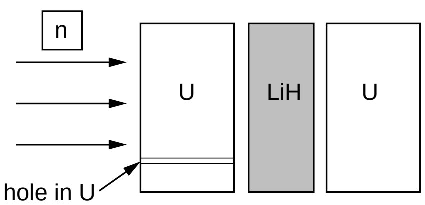


Fig. 1. Experimental setup for neutron-radiography test showing an LiH cylinder between uranium bricks.

The basic concept of high-energy neutron radiography involves the detection of irregularities in thick, heavy materials and in light materials embedded in them. We designed an experimental setup (Fig. 1) to test this concept. A 2.54-cm thick LiH cylinder was placed between two uranium bricks, each 5 cm thick. The LiH cylinder was positioned to cover approximately half the area between the bricks as depicted in Fig. 2. Three 12-, 8-, and 4-mm diameter holes (from left to right in Fig. 2) were drilled completely through the LiH cylinder. In addition, two 12- and 8-mm diameter holes (from left to right in Fig. 2) were drilled halfway through the LiH cylinder. The bricks were placed approximately 80 m from the WNR source, and the detector was located about 3 m from the bricks.

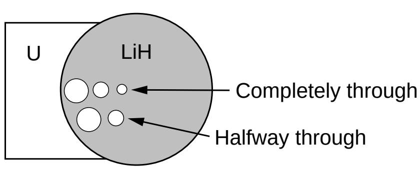


Fig. 2. View of an LiH cylinder face showing location, size, and depth of holes.

In addition, small holes with diameters of 40 mil (1 mm) and 69 mil (1.75 mm) were drilled through the uranium brick closest to the beam source (left image in Fig. 1). The drilling was done to examine the effect of small-angle (Mott-Schwinger) scattering on the produced image. The detector was constructed from existing components. The data-acquisition system used CAMAC (computer-automated measurement and control) analog-to-digital converters to read out the detectors. The system was triggered by a logic signal generated by three plastic scintillators.

A neutron interacts with the tungsten converter, and a proton is ejected (Fig. 3). A trigger is formed if the proton passes through the two scintillators S1 and S2. V is an additional scintillator that vetoes charged particles produced before the W converter. The (x,y) positions of the proton are determined in two adjacent multiwire detectors, MW1 and MW2. These coordinates then determine the point of origin of the proton on the tungsten converter or the point of origin of the neutron from which the proton was generated. The multiwire detectors have a characteristic resolution of approximately 1-mm full-width at half-maximum (FWHM). We estimate the effective energy range of detected neutrons to be between 40 and 600 MeV.

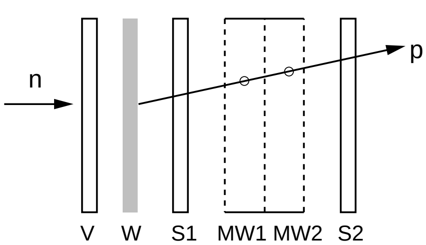


Fig. 3. Schematic of the operation of the neutron-imaging detector.

The data were analyzed and stored in two-dimensional (x versus y) arrays in 1-mm by 1-mm bins. Figure 4 depicts the relative transmission of neutrons (full circles) through the 69-mil diameter hole obtained in the experiment. The transmission is compared with the calculated value using a geometric transmission model (solid line). The resolution of the detector is broadened with a standard deviation of 800 mm. The scan is from top to bottom of the U face through the center of the hole.

Our initial calculations predict a 4% increase in the number of transmitted neutrons in the center of the through-holes in the LiH cylinder. Figure 5 shows the simulation calculation of the number of neutrons per square millimeter pixel, using total cross sections determined by previous measurements at WNR (right half of Fig. 5). These are "area plots" where equal neutron intensities are depicted by identical shading. The five circles of missing material in the LiH cylinder are evident, as is the edge of the LiH cylinder. The left half of Fig. 5 depicts the experimental results obtained by dividing the number of transmitted neutrons measured with the LiH cylinder in place by the number of neutrons with the LiH removed. The five holes are all evident, although the intensity change resulting from the shallower 8-mm-diam hole (lower right hole in Fig. 5) is close to the statistical limit.

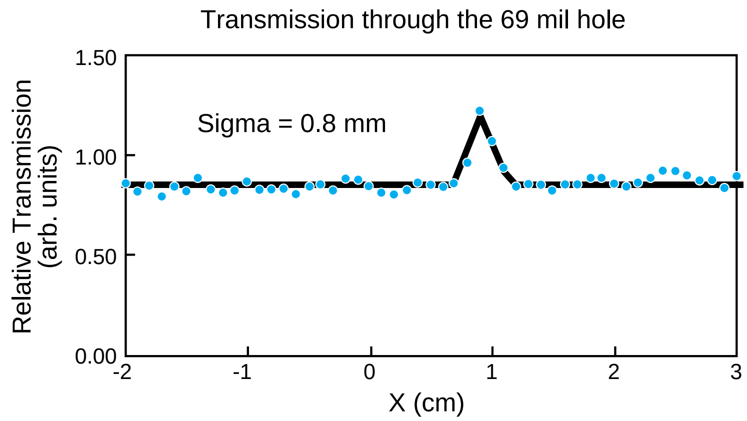


Fig. 4. Comparison of the theoretical (solid line) and experimental (full circles) neutron transmission through a uranium brick with a 69-mil diameter hole.

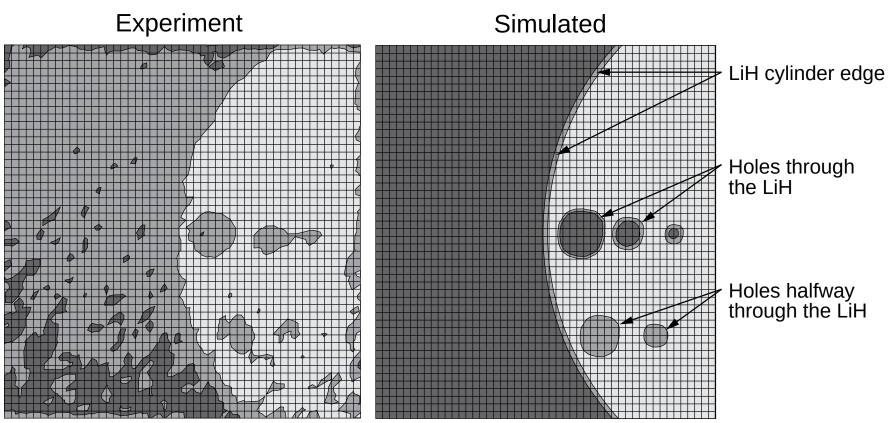


Fig. 5. Comparison of the experimental and calculated neutron transmission through an LiH cylinder using total cross sections measured at WNR.[1]

In summary, the basic physics principles behind high-energy neutron radiography have been corroborated. Our simple computational model is in reasonable agreement with the data we have obtained. In particular,

• small angle scattering is not a "show stopper," and

• we have seen cavities in LiH on the order of 0.3 cm^3. (With more efficient detectors, longer running time, and better data-acquisition systems, this limit could be pushed down much farther.)

Reference

1. R. W. Finlay *et al.*, "Neutron Total Cross Sections at Intermediate Energies," *Physical Review C* **47**, 237 (1993).

The Solar-Neutrino Puzzle

A. Hime, Weak Interaction Group (P-23)

History

By the mid 1920s, physicists shared the view that matter is composed of two basic constituents: electrons and protons. Of course, they were the only two particles known to exist at the time, and scientists were reluctant to postulate the existence of new particles without due cause. However, in beta decay, electrons were known to be ejected; one naturally assumed therefore that they must have been in the nucleus to begin with. Nonetheless, this early picture of subatomic matter met with tremendous difficulties. On the one hand, it was impossible to envision a force strong enough to bind an electron to a region as small as the atomic nucleus. Furthermore, arguments based upon spin and statistics were inconsistent with nuclei composed of protons and electrons alone.

Even more perplexing was the observation that electrons ejected in nuclear beta decay presented themselves with a continuous energy distribution, a baffling observation for a disintegration involving a single free particle in the final state. Indeed, the process suggested a violation of the law of energy conservation. The problem was resolved by Wolfgang Pauli in 1930 who offered a “desperate remedy” by conjecturing the existence of a new particle, which was later dubbed the neutrino by Enrico Fermi. The neutrino not only would solve the contradictions posed by spin and statistics but also would share the energy released in beta decay with electrons and thus rescue the coveted law of energy conservation.

Having no electric charge and virtually no mass, the neutrino was thought to be undetectable by most physicists. However, detection was accomplished by a Los Alamos group in 1956 only when very intense sources of neutrinos were realized at nuclear reactors. Since that time, the neutrino has played a fundamental role in elucidating our understanding of elementary particles, astrophysics, and cosmology.

Perhaps the most interesting modern quest is to determine whether neutrinos have mass. In the standard model of elementary particles, neutrinos are strictly massless. However, quests for a grand-unified theory of the fundamental forces of nature suggest that neutrinos, like other elementary particles, should have mass. Because neutrinos were produced in copious amounts in the early universe, they could contribute significantly to the energy density of the universe and play a decisive role in the ultimate fate of the universe.

To date, no clear evidence for neutrino mass exists despite years of painstaking work the world round. Experiments at Los Alamos during the 1980s provided precise measurements of tritium beta decay but were not able to find evidence for neutrino mass. However, these experiments ascertained that the mass of the neutrino emitted in beta decay is at least 50,000 times smaller than that of the electron. Los Alamos scientists continue their participation in international efforts to discover whether the neutrino holds the key to some of the most fundamental questions in modern physics.

The Solar-Neutrino Puzzle

Deep in its core, the Sun is host to proton-proton fusion reactions that release nuclear energy during a stepwise production of elements (up to ^8B), all of which subsequently decay with the release of photons (particles of light) and neutrinos. The energy released from these solar reactions takes millions of years to reach the Sun's surface; this energy is then radiated as sunlight. Neutrinos on the other hand interact feebly with matter and thus escape the Sun and reach Earth in about eight minutes traveling at the speed of light. Consequently, experiments that detect these solar neutrinos offer a unique probe of the innermost regions of a star and the details of the nuclear reactions that fuel them.

Experiments designed to detect solar neutrinos must use large detectors to overcome the tiny interaction probability of neutrinos with matter. The first of such experiments, which has been in progress for over twenty years, uses a large tank of cleaning fluid in which electron neutrinos from the Sun make themselves known by interacting with chlorine in the detector volume. A problem persists in that the number of neutrinos observed in the chlorine experiment falls significantly short of that predicted by the standard solar model (SSM).

Because the spectrum of neutrinos probed by the chlorine experiment is sensitive to the details of the SSM (particularly to the central temperature of the Sun), one might easily confess a lack in our understanding of the details of the Sun. Nonetheless, in more recent years three more solar-neutrino experiments have emerged, all of which have observed a deficit of neutrinos compared with predictions of the SSM. Although any one experiment is not sufficient to dismiss a problem with the SSM, the combined results from these four solar-neutrino experiments may have potentially radical consequences.

The different solar-neutrino experiments probe different windows of the neutrino energy spectrum produced at the heart of the Sun. In particular, experiments using gallium as the detecting material are sensitive to the main proton-proton fusion chain, a mode that is relatively insensitive to variations in the SSM. Physicists at Los Alamos have been the main U.S. contingent of the Russian-American gallium experiment (SAGE), which is currently in operation in southern Russia.

Taken together, the data from these solar-neutrino experiments indicate a solar-neutrino deficit that seems difficult to remedy by any astrophysical or nuclear-physics solution. Where have the missing neutrinos gone? An intriguing possibility is that the neutrinos created in the core of the Sun somehow change their identity on their way to Earth, thus eluding existing detectors. Such a possibility, known as neutrino oscillations, can exist because more than one type of neutrino does in fact exist. We now know of three different types of neutrinos: the electron neutrino, the muon neutrino, and the tau neutrino. Each one is named after its corresponding charged partners.

The Sun produces only electron neutrinos, and existing detectors are sensitive only to electron neutrinos. Consequently, if the electron neutrinos produced in the Sun were to oscillate into either muon or tau neutrinos during their flight to Earth, then the total number of neutrinos would remain fixed, but some fraction would not register in our terrestrial targets.

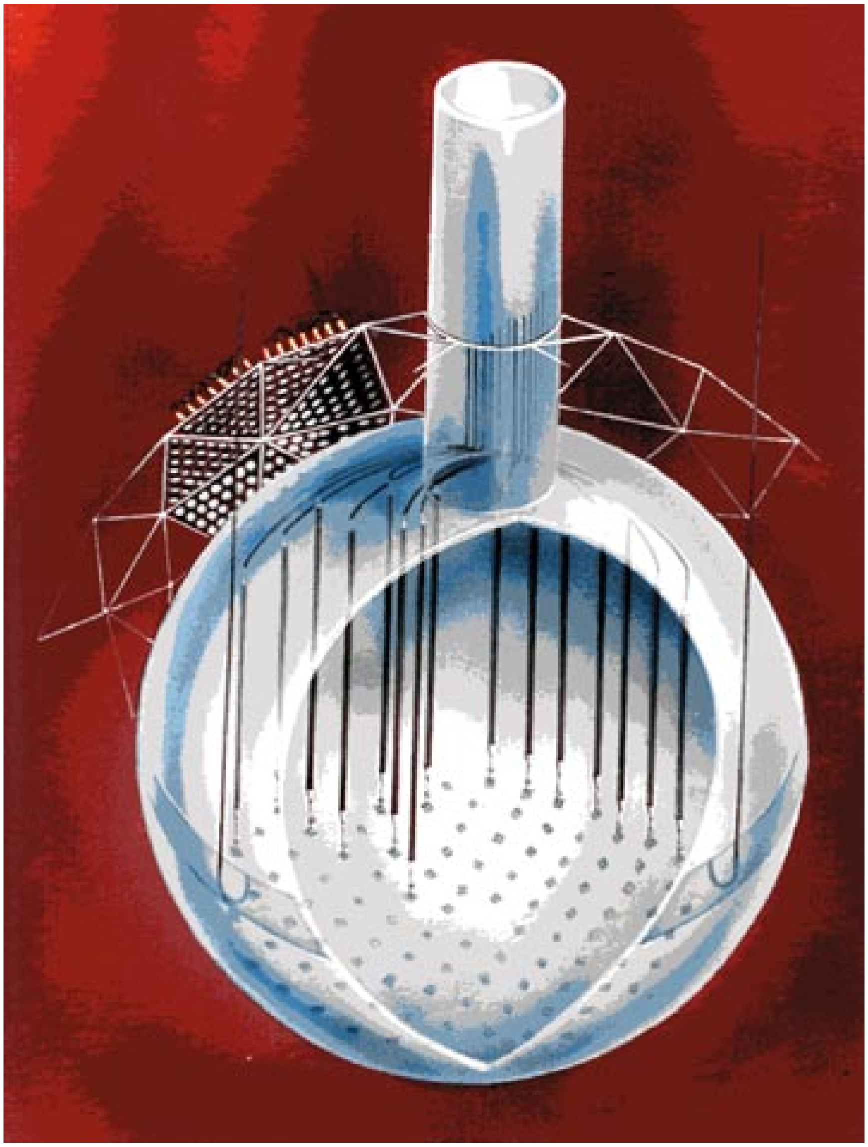
For neutrino oscillations to occur, the neutrinos themselves must possess mass. The standard model of elementary particles precludes the existence of neutrino mass in its simplest form. Despite its tremendous success, the standard model may only be an approximation to a deeper grand-unified theory of nature. Consequently, the discovery of neutrino mass would provide the first hint of physics beyond the standard model and offer guidance to a more fundamental understanding of nature.

The Sudbury Neutrino Observatory

If neutrinos are oscillating from one "flavor" to another, then experiments must have the capability of detecting not only the electron neutrinos but also the neutrino flavors that they may oscillate with. The Sudbury Neutrino Observatory (SNO), which is presently under construction by collaborators in Canada, the U.S., and the United Kingdom, is such a detector. The heart of the SNO detector is 1,000 tonnes of heavy water, which allows sensitivity to all three flavors of neutrinos through two unique interactions with deuterium.

The SNO detector is situated 6,800 feet underground in a nickel mine near Sudbury, Ontario, to escape interactions from cosmic-ray particles. The central part of the detector is a 12-m-diam sphere that will be assembled from ultrapure acrylic panels. This acrylic vessel will house the 1,000 tonnes of heavy water that will be used as a neutrino target. The central volume of heavy water is shielded from natural radioactivity in the surrounding cavity by a secondary vessel containing 8,000 tonnes of regular (light) water.

Fig. 1. An artist's rendition of the central volume of the SNO detector, which is presently under construction in the Creighton nickel mine near Sudbury, Ontario. The spherical acrylic vessel will house 1,000 tonnes of heavy water. Surrounding the vessel are 9,800 photomultiplier tubes used to detect the Cerenkov light produced by charged-current interactions of neutrinos. An 800-m array of ^{3}He proportional counters will be distributed throughout the heavy water to independently detect neutrons produced by the neutral-current interaction of neutrinos.



When an electron neutrino interacts with a deuterium atom in the heavy water, an energetic electron is ejected via the charged-current interaction. This interaction produces Cerenkov light, which is subsequently detected in an array of 9,800 photomultiplier tubes that surround the acrylic vessel. Neutrinos of all flavors can interact with deuterium via the neutral-current interaction to liberate a free neutron. Detection of this neutron then allows us to compare the neutral-current rate with the charged-current rate; this comparison gives us a conclusive statement as to whether or not electron neutrinos are oscillating into other flavors on their route from the Sun to Earth.

Los Alamos physicists, together with SNO collaborators at the University of Washington, are presently engaged in a program to construct and deploy ^{3}He proportional counters into SNO to detect the neutrons liberated by neutral-current neutrino interactions in the heavy water (Fig. 1). Although the use of ^{3}He proportional counters in nuclear and particle physics represents a well-practiced art, their use in the SNO detector must meet many unconventional and untried constraints. For example, because only about 14 solar-neutrino events per day are expected, the detectors must be made from ultraclean materials, whereby the natural levels of uranium and thorium must be smaller than parts per trillion by weight. Consequently, detectors will be fabricated via a special chemical deposition process involving ultrapure nickel.

Measurements with prototype detectors in our underground test facility at the Waste Isolation Pilot Plant near Carlsbad, New Mexico, have demonstrated that the materials, which will be used to construct proportional counters for SNO, meet the requirements for radioactivity and are about 200 times cleaner than any previously constructed device. An interesting spin-off from this research has appeared in connection with the microelectronics industry. Apparently, new-generation computer chips are thin enough that the decay of natural radioactive elements in the construction materials can create single bit flips from one binary number to another. Consequently, the Los Alamos neutrino physics group will apply its knowledge to provide ultralow-background particle detectors for screening microelectronics components.

Although construction materials for the SNO detector must meet unprecedented standards of cleanliness, the ^{3}He detectors are also large relative to conventional applications. The neutral-current detector array will employ the equivalent of 800 m of proportional counter dispersed uniformly throughout the SNO acrylic vessel. Each detector string is up to 11 m in length.

The elusive neutrino has tempted and intrigued physicists for more than 60 years since it was first postulated by Pauli. The present conundrum surrounding the missing solar neutrinos points to the possibility of some very exciting discoveries in the next generation of experiments such as SNO. By the end of this decade, the properties of the neutrino that at one time seemed undetectable may soon be revealed and offer a long-awaited clue to some of the fundamental mysteries of the universe.

Archiving Nuclear Tests

M. L. Stelts (P-23), K. C. Croasdell (P-22)

Historical Perspective

Los Alamos National Laboratory (LANL) has traditionally been responsible for the certification of our nuclear stockpile. With the cessation of nuclear testing, this task has become much more difficult. The charge of the Scientific-Based Stockpile Stewardship (SBSS) requires the certification of how the weapons perform as they age without the benefit of actual testing. Valid and realistic computational models of the performance of nuclear devices are required before any confidence can be gained in calculating the effects of aging on the weapons.

Over the last few decades, the approach to nuclear-weapons design was largely empirical. Nuclear testing at the Nevada Test Site (NTS) allowed for the refinement and efficiency of nuclear devices, the performance of which is very complex. Codes and physical models were not adequate enough for calculating device performance from first principles. Nuclear testing established empirical parameters for interpolative calculations. Much of the diagnostic data obtained were not incorporated into the physical modeling because of the inadequacies of the computational tools. Presently, more powerful computers and more sophisticated models are available, but the codes must be compared with the experiment before they can be used to calculate effects of aging or design modifications of the nuclear stockpile as mandated by SBSS.

Current aboveground experiments (AGEX) cannot approach the energies achieved in a nuclear test by many orders of magnitude. There is an ongoing effort to understand the physics of nuclear weapons through these AGEX experiments. However, the only realistic approach is to use these experiments as supplements to the nuclear-test data. Matching data taken on real nuclear devices is necessary to validate the codes and models. Our goal is to recover as much nuclear-test data as possible and make them easily available to the design community.

Some of the diagnostics used to test weapons now in the nuclear stockpile were developed in the 1970s. Many people who worked on the diagnostics retired or are deceased. Moreover, methods of performing experiments and acquiring data have changed over the years. For example, the use of computers for analysis and storage of the data was rather minimal in the 1970s; at the cessation of testing, computers were used extensively for the acquisition, analysis, and storage of data. In the diagnostic area, there were no standards or procedures for the archival of data and associated information. More emphasis was placed on preparing for the next experiment rather than documenting the previous one.

Experimental Data

Fig. 1. A typical experimental rack before installation in the tower. The nuclear-device canister is attached at the bottom, and the PINEX box is attached at the top. Cables were not yet attached at this point. Some of the many LOS and shielding cans are visible.

Historically, P Division has been responsible for designing the prompt diagnostics for underground nuclear tests. Some diagnostics were performed rather routinely. Figure 1 shows the equipment rack for a typical experiment. Often the suite of diagnostics made the rack quite complicated and therefore much attention was paid to the interaction between experiments and adequate shielding. The rack was buried to depths ranging from a few hundred meters to about 800 m. Signals were transmitted through coaxial cables or fiber-optic links to recording trailers. The time scale and the energy of these events were exceedingly fast—the detectors were typically destroyed before the signals had reached the recording trailers.

The object of the experiments was to obtain data that were sensitive to the physics of the hydrodynamic and burn processes that took place in the explosion. All the prompt diagnostic experiments measured leakage of some kind of radiation (γ-rays, x-rays, or neutrons) from the device. Because the sources of radiation are generally quite thick compared with the mean-free path of the radiation, the observed leakage must be compared with detailed transport calculation of the radiation through the exploding device. Hence, the lines of sight (LOS) of the various experiments and the detector responses and sensitivities must be characterized quite carefully.

P-22 (and predecessors) has had primary responsibility for acquiring reaction history (RH) data. RH is essentially a measurement of the γ-ray flux from a source typically over at least 10 orders of magnitude. The emphasis was on shape such that α, the logarithmic derivative of the flux curve, could be measured with precision. Many detectors in several LOS were needed to achieve this wide dynamic range. This experiment was also generally chartered to measure interval times between components in a device.

P-23 (and predecessors) was responsible for measurements involving neutron leakage. Experiments at the NTS incorporated a number of unique diagnostics, including PINEX, NUEX, and THREX. The PINEX diagnostic combined a pinhole, radiation-to-light converter, and TV cameras to capture images of the burn of nuclear devices. PINEX was used to return several types of images, including time-integrated pictures of fusion-neutron output. The diagnostic's fast-shuttering capability allowed for the acquisition of time-resolved images during the time of burn or as a function of neutron energy, depending on the flight path of the neutrons to the image fluor. Spatially integrated data obtained with detectors in the PINEX diagnostic box allowed for the maximum time-of-flight dispersion versus neutron energy and hence the highest neutron-energy resolution. Images of the γ-ray and x-ray output of sources were also taken. NUEX and THREX diagnostics, which mostly comprised proton-recoil telescopes (PRT) that collected recoil protons from hydrogenous material, measured neutron leakage from various regions of the nuclear device. Before the PRT technique was developed in the mid 1970s at the NTS, such measurements were made by detecting fission fragments from neutron-induced fission on various fissionable materials. The THREX diagnostic, which generally comprised silicon PIN diodes, was much more sensitive than the typical NUEX diagnostic, which used Faraday cups. The diagnostics can be configured as needed to return data that are sensitive to either the spectrum of neutrons emitted or to the time history of leakage from the source, or both.

Both P-22 and P-23 performed special experiments beyond this standard set of diagnostics, which returned data useful for the understanding of the physics of these devices.

Content and Structure of the Archive

One aspect of the archival process common to all experiments is the documentation of the LOS to define the field of view of the experiment at the source, the solid angle for the radiation that enters the experimental package, and any materials in the LOS that would absorb the radiation. Most of the NTS experiments involved the conversion of radiation to an electrical current. The recording system needed to be characterized so that precision measurements of the electrical signals from the detector could be made. This characterization involved the time response of the recording system, cross timing between experiments, and the sensitivities of the various recording instruments.

The characterization of the response of the detectors might have been quite different depending on the details of the various experiments. The time and energy responses of detectors needed to be characterized or calculated. They were derived either from experimental measurements or calculated from detector parameters. In either case, these responses must be documented in the archive in order to fold them with the calculated flux to produce calculations to compare with data. For each experiment, we are producing procedure files that detail the steps needed to compare a time- and energy-dependent flux with the experimental data. Important documents, reports, notes, etc., pertaining to the experiment are electronically scanned and added to the archive.

Groups P-22 and P-23 are responsible for their own archival data base. Access to the data by other groups is based on a “need-to-know” basis. The structure of the archive is hierarchical, organized by shot name, experiment, and other subdirectories as needed to logically organize the data. One section is devoted to information common to many different events. Text files are used to document data and experimental parameters and to explain the results. Each directory and subdirectory has a table of contents detailing what is in the directory and its subdirectories. This information, derived from the table of contents, is entered into a Laboratory-wide data base, known as COEDS, to provide the weapons community pointers to the data. Computational tools, another important aspect of the archive project, must be maintained to analyze data, compute response functions, and transform the theoretical calculations into a form that can be compared with data.

The Future

The job of nuclear archiving is formidable with literally hundreds of experiments to document and with reanalysis of data often necessary. This effort will continue for some years. A related task involves the production of documents that describe the "why" and "how" of each experimental technique. Both the rationale and the method for interpretation of the data must be detailed. In the meantime, we have put procedures in place for archiving this most valuable data and have completed the documentation of several experiments.

The Physics Division is only one portion of the archival effort. There are seven LANL Divisions involved in archiving areas such as materials, device construction, and various testing procedures, including hydrodynamic PIN shots and PHERMEX tests. Other Department of Energy laboratories are also working to archive their data. Clearly, archiving nuclear tests is an important aspect of SBSS and will continue for some years.

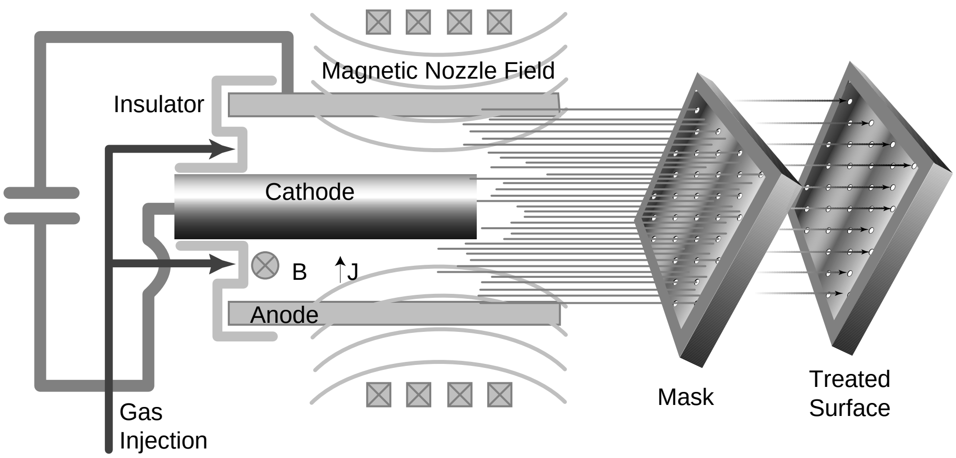
Accelerated Plasmas and Intense Ion Beams for Commercial Processing

H. A. Davis, J. T. Scheuer, K. F. Schoenberg (P-24)

Introduction

Two technologies using intense-pulsed streams of particles are being developed in Group P-24 primarily as flash-heat sources for the advanced and environmentally conscious commercial processing of materials. The first technology, the coaxial plasma accelerator (Fig. 1), is a simple, compact, and mechanically robust device that uses the Lorentz force (j x B) to impulsively accelerate plasma to very high velocities (1 to 5 cm/µs). The plasma is produced in a coaxial accelerator by discharging energy from a capacitor bank with a few kJ of stored energy through a gas puff injected into the muzzle region of the gun. Radial current flow and the azimuthal self-magnetic field give rise to an axial acceleration of the plasma. Typical ion energies are in the range of 10 to 100 eV with 0.1 to 1.0 J/cm^2 delivered to the target in a few microseconds. Any gas species can be used to generate the plasma, but typically a nonreactive species such as argon is used. A thin skin of energy from the plasma is deposited on the surface of the target and is transported into the bulk of the material through thermal conduction.

Fig. 1. Coaxial plasma accelerator showing the application to patterned etching.



The second technology uses an intense ion beam with higher particle energy and energy density at the target than accelerated plasmas. As shown in Fig. 2, the beam is produced by accelerating the ions in a diode. The anode of the diode consists of a dielectric ring inserted inside an aluminum plate. The cathodes consist of the tips of two thin concentric conical sections. Just before the accelerating voltage is applied, a fast-risetime (200-µs) magnetic field of a few kG is applied transverse to the anode-cathode gap by two magnetic field coils: one located inside the inner cone and one located outside the outer cone. At the peak magnetic field, a positive accelerating voltage from a Marx generator is applied to the anode. A combination of tangential electric fields at the anode surface and weak electron loss to the anode cause the dielectric anode insert to flashover, providing a source of ions for the beam. The applied magnetic-field strength is adjusted to prevent electrons from crossing the anode-cathode gap, but the more massive ions, which are only very weakly deflected by the magnetic field, are ballistically focused to a spot located 35 cm from the anode. Peak particle energy is 400 keV with up to 30 J/cm^2 delivered to the target over a 10-cm-diam spot. The 1-µs beam is composed of a combination of protons and carbon and oxygen ions. Beam energy is deposited in targets over typically a 1-µm ion range. This range is much deeper than that of the accelerated plasmas. Thermal conduction into the target is relatively unimportant for many target materials.

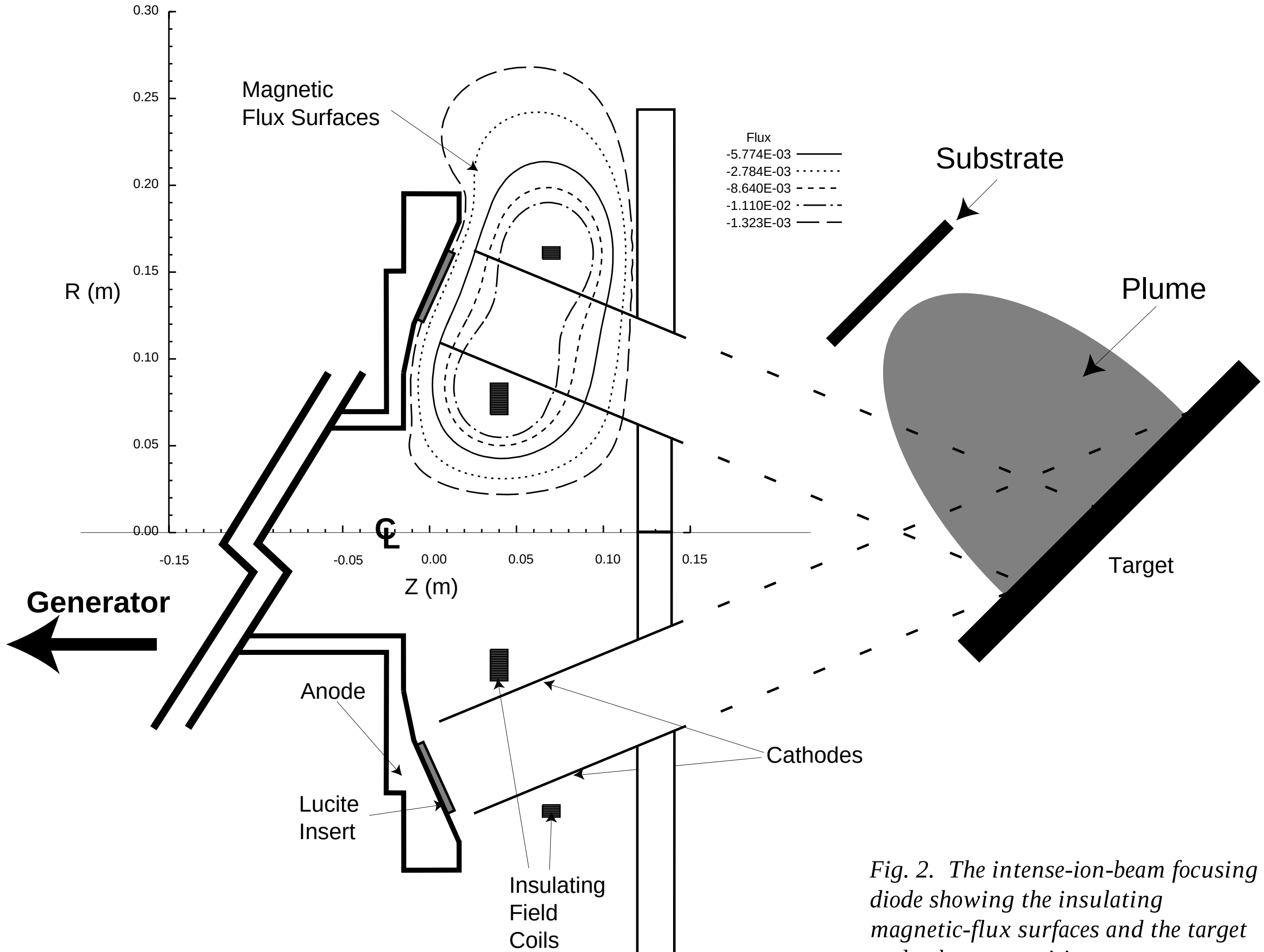


Fig. 2. The intense-ion-beam focusing diode showing the insulating magnetic-flux surfaces and the target and substrate positions.

Accelerated Plasma Applications

The heat pulse delivered to a target by accelerated plasmas can be used to modify the chemistry, crystal morphology, topography, or density of the thin surface layer of a target material while not affecting the underlying bulk properties of the material. One key application is large-area patterned etching of thin-surface deposited layers as shown in Fig. 1. This technology provides clear advantages over conventional "wet" chemical etching techniques by being more environmentally benign and for potentially reducing manufacturing costs per component. Furthermore, accelerated plasmas offer significant cost advantages over competing advanced etching technologies by virtue of their high-energy deposition and broad-area coverage on the target, which provide very high etch rates with concomitant high-manufacturing throughput. However, full commercialization of accelerator technology requires the means to control the distribution of directed energy on a target located downstream of the accelerator.

Magnetic nozzles hold great promise for the enhanced control necessary for manufacturing applications. Conceptually, the magnetic nozzle is analogous to a gas-dynamic nozzle, where the nozzle shape can modify flow-velocity and flow-streamline distributions, both within the accelerator and downstream of the accelerator. Recent Los Alamos research using numerical simulation with experiments on the CTX (compact torus experiment) coaxial plasma accelerator demonstrated that magnetic nozzles provide a method to improve accelerator reproducibility, efficiency, and energy / power distribution on a downstream target. For example, without the benefit of a magnetic nozzle, plasma accelerators typically concentrate energy along the axis of symmetry of the device. This “magnetic pinching” results in an undesirable nonuniform energy distribution on the target. Magnetic nozzles can reduce magnetic pinching and spread the plasma plume evenly over a wide area, resulting in a more uniform energy distribution at the target. A new accelerator with industrially relevant size and parameters, currently under development at Los Alamos, will be used to investigate materials applications and to study the fundamental physics of magnetic nozzles.

Intense Ion Beam Applications

There are two primary materials treatment methods that use intense-ion beams as flash-heat sources. In the first, the ion beam is focused on a target to rapidly heat and vaporize target material. The energetic ions deposit their energy in a typical depth of 1 µm; the target material is heated to tens of eV. The vaporized and ionized material expands in a plume normal to the surface of the target and is condensed onto a substrate forming a high-quality film. The numerous advantages of this type of deposition process over standard vapor deposition include the following:

- very high rates and low cost are possible;
- very energetic, strongly ionized plume material allows for the formation of materials unattainable otherwise (*e.g.*, the formation of diamond-like carbon requires a minimum kinetic energy of about 10 eV);
- target-to-substrate stoichiometry is preserved (congruent deposition) and allows for the formation of complex films (*e.g.*, high-temperature superconducting materials); and
- crucibles and filaments are eliminated, and thus film purity is improved.

The process is similar to the well-established pulsed laser deposition (PLD), but it has a number of advantages over the laser technique. The total energy of the beam is much higher, there is no reflected energy (*i.e.*, much of the laser energy can be reflected from the target), and ion-beam production is cheaper and more efficient than with the eximer lasers required for PLD. Pulsed ion beam deposition is estimated to be a few hundred to a few thousand times cheaper than PLD and will have much higher throughput. Experiments at Los Alamos have demonstrated, for example, the deposition of diamond-like carbon (*e.g.*, for field-emissive displays, candidates for the next generation of high-definition, flat-panel displays) at 1-mm / s instantaneous rates with state-of-the-art electron-emission properties and the congruent deposition of $YBa_2Cu_3O_{7-x}$ (1-2-3) superconducting material.

The second process uses ion beams for surface treatment of solids. Here an intense ion beam rapidly melts the near surface of the target. Thermal diffusion is minimized by employing pulses of less than 1.0-µs duration. Rapid resolidification of the target material produces amorphous layers, dissolves precipitates, and forms nonequilibrium microstructures. Experiments at Los Alamos and elsewhere have demonstrated a threefold increase in the hardness of O1 tool steel, a more than sixfold increase in the pitting time of 2024-T3 aluminum alloy, and a decrease in surface roughness of Ti-6Al-4V from 5 to 0.1 µm. Also, we have used ion beams to alter the surface texture of polymers (*e.g.*, to improve adhesion or wetting). The increase in the surface hardness of polymers by a factor of 20 has been demonstrated at Oak Ridge National Laboratory through cross-linking; this accomplishment will, for example, open the way for processing polymer stamping dies.

The next step in demonstrating commercial viability is to move from our current single-shot capability to repetitive high-average-power beam technology. When achieved this will open the door to high-payoff applications such as low-cost photovoltaics and advanced composite materials. High-average power technology requires two new elements: (1) a diode capable of repetitive firing and (2) a modulator system to drive the diode. Of the two new elements, the diode is the most complex. The surface-flashover diode currently used, an inherently single-shot device, will be replaced with an active-anode plasma source whereby the anode is the surface of a plasma generated on each pulse. The anode cannot erode, the ion species can be selected readily (*i.e.*, any gas can be used), and the beam should be much more uniform and reproducible because the unreliable flashover process is eliminated.

The Role of Symmetry in Indirect-Drive Laser Fusion

A. A. Hauer, N. D. Delamater, T. N. Archuleta, S. C. Evans, W. W. Hsing, J. L. Jimerson, J. A. Oertel, G. Petersen, T. J. Sedillo, R. G. Watt (P-24)

It is not surprising that a property as all pervasive in physics as symmetry should be one of the key requirements for the achievement of thermonuclear fusion in the laboratory. The field of inertial fusion is at a potentially exciting threshold because ignition conditions will possibly be achieved in the laboratory within the next decade. The conditions required for ignition are fairly well understood and would be produced in high-density, high-temperature implosions driven by lasers or by some form of particle accelerator. The two principal approaches to delivering the high energy density needed to drive the implosions are illustrated in Fig. 1. The direct-drive approach applies the energy directly to the outer surface of a capsule, which contains the fusion fuel. Indirect drive uses the heating of the walls of a radiation cavity known as a hohlraum. The x-rays produced at the walls of the hohlraum are absorbed on the surface of the capsule and implode it. Regardless of how the energy is delivered, it must be very uniformly distributed on the surface of the capsule. In other words, there must be excellent drive symmetry.

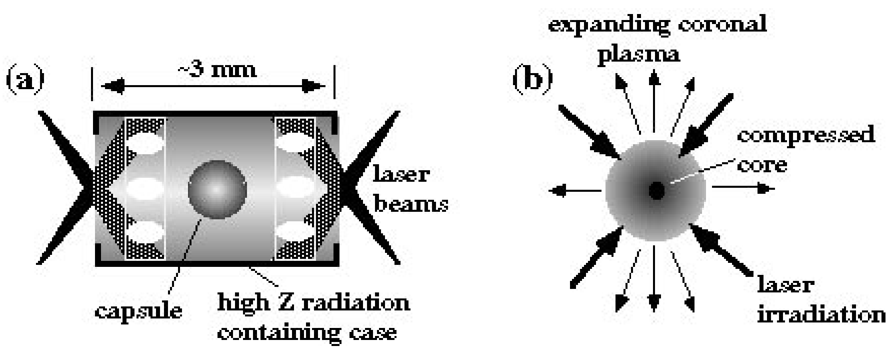


Fig. 1. Indirect-drive (a) and direct-drive (b) laser fusion concepts. In (a), the spots represent laser beams incident on the inner walls of the hohlraum.

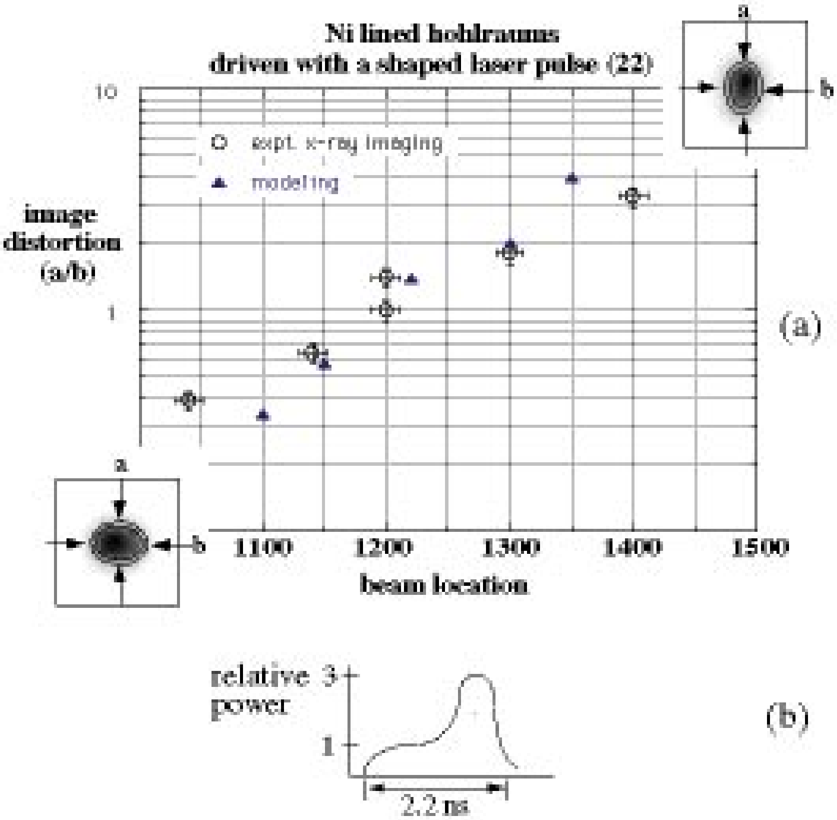
Over the last several years, groups P-24, X-1, and others at Los Alamos have collaborated with researchers at Lawrence Livermore National Laboratory (LLNL) in an intensive series of experiments dealing with the subject of symmetry requirements in laboratory inertial fusion. A hallmark of this work has been the extremely close connection between experimental measurements and theoretical modeling. Theoretical modeling provides a very good indicator of the bounds for ignition-target performance but does not allow the prediction of the exact laser and target conditions that will produce optimum symmetry. These conditions will have to be determined experimentally. A significant effort has been devoted to developing measurement techniques to make symmetry tuning possible. These techniques have been applied to a series of experiments that give a graphic picture of the symmetry conditions in the complex hohlraum environment. These experiments have been compared with detailed, fully integrated theoretical modeling. The ultimate goal of this work is the detailed understanding of symmetry conditions and the methods used for their control.

A rough indication of the degree of symmetry required can be obtained from very simple considerations. Most current ignition-target designs envision a configuration of the compressed fuel that has a high-temperature “hot spot” in the center (comprising about 0.1 to 0.2 of the total fuel mass) surrounded by a layer of cooler but very dense material. Within this hot spot, the temperature and density must be high enough to initiate a significant number of fusion reactions and to trap the resultant α particles. The work done by the implosion must create these conditions. For current target design (having input laser energy of about 1.8 MJ), these conditions require a hot-spot convergence ratio C_r (initial radius / compressed radius) of ~ 30 to 40. The implosion velocity must be uniform to about one-half to one-forth of the convergence ratio to have a reasonable configuration of the hot spot that is neither too aspherical nor broken up into “jets.” From simple models for the “rocket-like” drive of an implosion, such a uniformity in the implosion velocity translates to an x-ray flux uniformity on the capsule of 1 to 2%.

The radiation environment of a laser-heated hohlraum departs from an ideal blackbody cavity for three fundamental reasons: (1) the laser entrance holes create a significant “sink” for radiation, (2) the hohlraum fills with plasma, which can refract the laser beams or change the position where the hottest sources of soft x-rays are created, and (3) the light must be deposited (focused) in localized regions on the inner surface of the hohlraum so that the laser light can be efficiently converted to soft x-rays. If the laser focusing and pointing are changed, the regions of laser deposition can be moved to compensate for the effect of the entrance holes.

Accurate methods need to be developed for measuring drive symmetry to compensate for the nonideal environment of a laser-heated hohlraum. The drive-symmetry measurement techniques developed thus far fall into three general categories: (1) direct use of an implosion by placing a capsule in the hohlraum, imploding it, and observing the spatial configuration of the compressed core plasma with x-ray imaging; (2) observation of the soft x-ray emission from the sources created by the laser inside the hohlraum or of re-emission from surrogate targets placed in the hohlraum; and (3) observation of the shocks in the capsule created by the hohlraum radiation field.

The typical geometry encountered in current symmetry-tuning experiments (on the Nova laser at LLNL) is illustrated in the left-hand portion of Fig. 1. Five beams enter each side of a cylindrical hohlraum and form two cones that can be thought of as illuminating the hohlraum with two “rings” of light. The regions directly illuminated by the laser produce a high-temperature plasma, which initially becomes the dominant source of soft x-rays. These initial x-rays illuminate the rest of the interior, heating the walls and therefore distributing sources of x-rays more evenly throughout the hohlraum. The regions irradiated by the laser, however, are always somewhat hotter than the surrounding walls. The simplest form of symmetry tuning is thus an exercise in properly positioning and focusing the input laser beams to compensate for the entrance holes and to produce good time-average drive symmetry. Perturbations (from spherical) in the flux distribution at the capsule surface will be reflected in a characteristic geometrical distortion of the compressed core plasma. The imploded core of the radiation-driven implosion is heated to about a kV in current experiments so the spatial configuration of the core is assessed by imaging it in self-emission in the 3- to 4-keV spectral range. Figure 2 illustrates typical x-ray image data taken while the drive symmetry in a hohlraum is being tuned by varying the location of the laser beams in the hohlraum. Also shown is the comparison with theoretical modeling. The beam location plotted on the x-axis is the position of the “rings” of illumination with respect to the position of the capsule. The image data shown illustrates the configuration of the compressed core for the extremes of pointing. The top right image shows the effect of a radiation-driven implosion that is hotter along the axis of the hohlraum as the capsule is compressed into an



upright oblate geometry, and the bottom left image shows the effect of a radiation-driven implosion that is hotter along the equator of the hohlraum.

The data described thus far have only dealt with time-integrated drive-symmetry conditions. Achieving ignition requires an understanding of possible temporal fluctuations in the symmetry. The implosion measurement method can also be applied to this problem through the use of sampling techniques that have been developed by P and X Divisions. One such technique employs imploding capsules with a variety of different wall thicknesses, which in turn have different implosion velocities. The rapidly imploding capsules sample only the early portions of the drive. In the early phase of a typical evolution, the regions of the hohlraum walls outside the laser spots are significantly cooler than the regions directly heated by the laser. The hot spots under the laser beams tend to dominate the x-ray drive and cause it to become "hot" on the equator of the hohlraum. Figure 3 shows the results of this sampling technique.

The measurement techniques that have been described here, combined with others that have been developed as part of this program, provide the basis for ignition-level experiments.

Fig. 2. Results of a typical symmetry tuning experiment compared with two-dimensional radiation hydrodynamic modeling are shown in Fig. 2a. The temporal profile of the laser drive pulse used to obtain this data is shown in Fig. 2b.

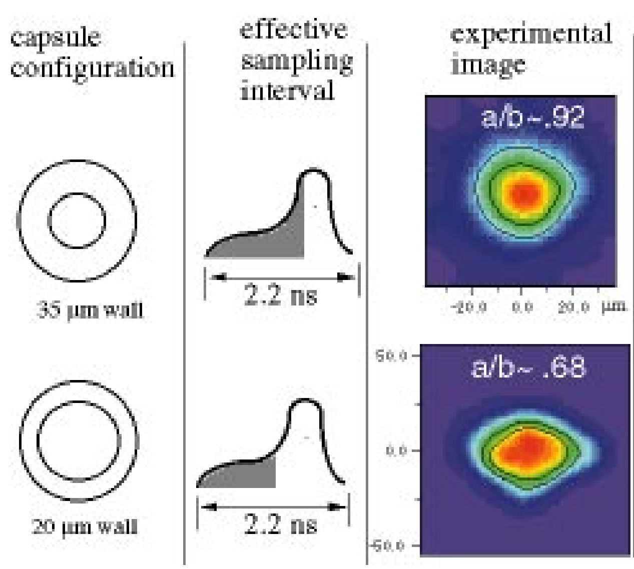


Fig. 3. Experimental data illustrating the "symmetry-capsule" sampling method for measuring time-varying drive symmetry. The shaded portions of the temporal profiles are estimates of the portion of drive sampled by the implosion of that particular target. For these two cases, theoretical modeling resulted in distortion ratios (a/b) of 0.96 and 0.71, respectively.

Space-Resolved Triton Burn-Up Measurements on the JT-60U Tokamak

G. A. Wurden, C. W. Barnes, R. E. Chrien (P-24), W. C. Sailor (TSA-3), G. Morgan (P-23), M. Lavelle (EG&G Las Vegas Energy Measurements, Inc.), A. L. Roquemore (Princeton Plasma Physics Laboratory), T. Nishitani, T. Kondoh, M. Hoek, H. Harano (Japan Atomic Energy Research Institute)

The confinement of charged particles is extremely important to the success of a magnetic fusion reactor. The fate of energetic charged particles produced in fusion reactions is especially crucial because these reaction products can slow down in the plasma and cause substantial heating of the background plasma. Indeed, "fusion burn" and "plasma ignition" relate to the condition when the heating caused by the alpha particles produced from DT (deuterium-tritium) reactions is significant and sufficient to maintain the plasma temperature without external heating. A variety of energetic fusion particles are produced depending on the fuel used for the nuclear reactions and on the branching between different reaction pathways (Table 1).

Table 1

Fusion Reaction	Energy Release (Q)	Reaction Products
$D + D \rightarrow T + p$	4 MeV	1.0-MeV triton 3.0-MeV proton
$D + D \rightarrow {}^3He + n$	3.25 MeV	0.825-MeV ^3He 2.45-MeV neutron
$D + {}^3He \rightarrow {}^4He + p$	18.3 MeV	3.67-MeV alpha 14.67-MeV proton
$D + T \rightarrow {}^4He + n$	17.6 MeV	3.5-MeV alpha 14.1-MeV neutron

Common Nuclear Reactions Using Deuterium Fuel

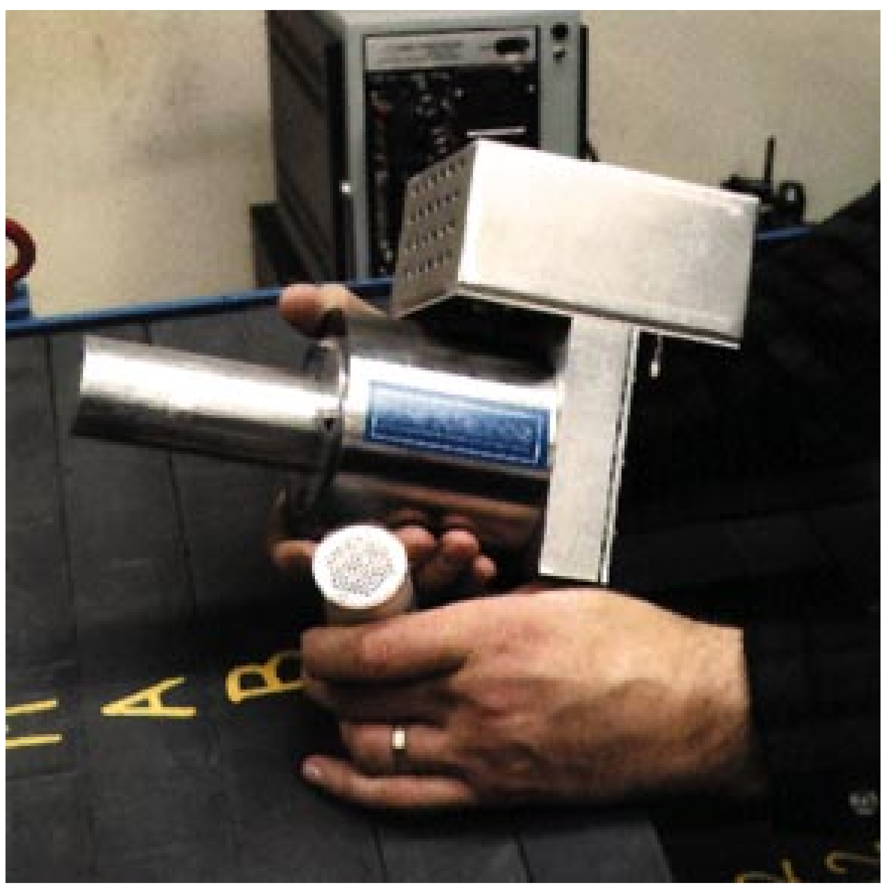
We have had a program in Group P-24, Plasma Physics, to study fusion reaction products on large tokamaks for a number of years. One element of this effort has been to develop better fusion-product detectors, which can either be more compact, directional, or less sensitive to interference from other forms of radiation. In the last 15 years, a particularly useful fusion diagnostic has measured the DT reactions occurring in a DD (deuterium-deuterium) fueled tokamak.[1] These DT reactions are caused by the interaction of the energetic tritons generated by DD fusion events, which then collide and fuse with a background deuterium ion in the plasma. The energetic 14-MeV neutron escapes from the plasma, and a neutron detector is used to detect the event. This detector discriminates against the more abundant (about 100 times more prevalent) 2.45-MeV DD neutrons and the accompanying hard gamma rays.

Typically, thin silicon diodes,[2] or liquid or thick plastic scintillators,[3] have been used to detect the large pulses produced by the 14-MeV neutrons. However, these detectors are nondirectional and need large collimators to obtain spatial resolution and heavy shielding to reduce gamma effects. The semiconductor sensor is also very susceptible to neutron damage and must be replaced often, even in DD-fueled tokamaks. Consequently, when we came across a 1966 paper[4] describing the use of scintillating plastic filaments in a directional neutron detector for space-flight applications, we realized that the combination of an old idea and new fiber-optic technology may improve a 14-MeV neutron detector suitable for use on today's tokamaks. We proceeded to model, design, build, and test such a detector at Los Alamos.

The concept is simple. By making a "composite" sensor head, we hoped to make a compact, directional 14-MeV neutron detector with improved gamma rejection and high count-rate capability to discriminate against more numerous 2.5-MeV neutrons from a hot DD plasma.

In a bulk plastic scintillator, an incoming neutron kicks out a recoil proton, which is heavily ionizing, and a large light pulse per unit energy results. For a 14-MeV neutron, the maximum proton-recoil track length is 2.2 mm from a head-on recoil. Some of this energy, which is converted to light by the scintillator, can be detected by a photomultiplier. However, the bulk scintillator responds equally well to neutrons from all directions. So to make a directional detector, we use a scintillator geometry that is long in one direction (*i.e.*, 10 cm is one mean-free path for a 14-MeV neutron to interact in the plastic) and yet short compared with the proton recoil in the other two dimensions (*i.e.*, 1.0- or 0.5-mm-diam scintillating fiber). Consequently, the maximum pulse of light will depend on the direction of the incident neutron. Furthermore, the fiber optic will now transmit the light down to the end where a photomultiplier tube or other light detector resides.

*Fig. 1. The compact scintillating-fiber 14-MeV neutron detector (*i.e.*, sensor, photomultiplier-tube case, and high-current electronics package) is shown in the background, and the fiber-optic/ aluminum-matrix sensor head is shown in the foreground.*



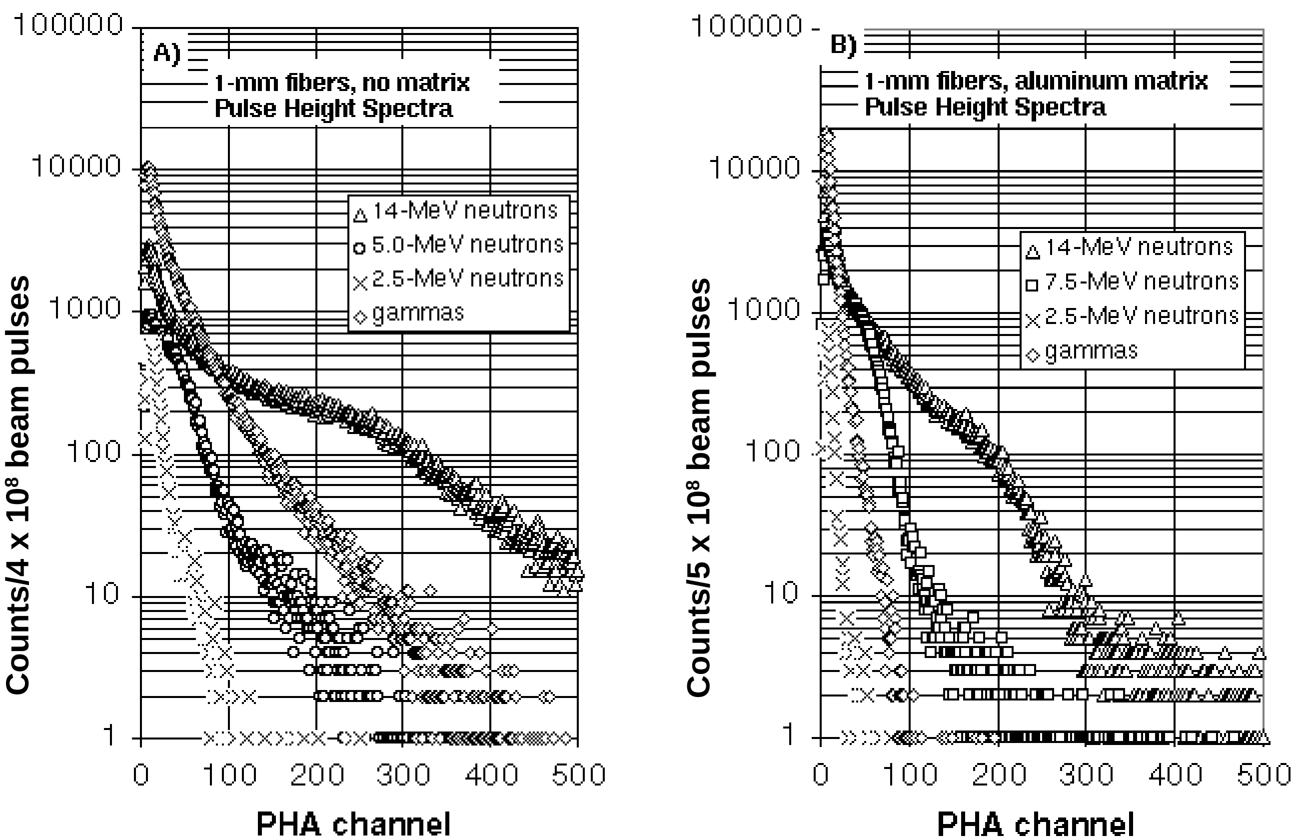
By selecting a number of fibers, we can adjust the overall system sensitivity. (We used 91 fibers in a matrix of aluminum.) To eliminate the "cross talk" between adjacent fibers, we placed sufficient opaque medium-Z material between adjoining fibers to stop the recoil protons, which result from off-axis neutrons or from off-axis recoil collisions. Figure 1 is a photograph of one of our production detectors. It shows the sensor head, the housing for a compact 2-diam Hammamatsu R-2490-05 magnetic-field insensitive photomultiplier, and the active electronics package.

The second problem with a bulk scintillator is that even though it detects neutrons well, it is also very effective at detecting gamma rays. A tokamak environment has a lot of material (*e.g.*, coils, structures, shielding) around the machine and in the test cell. As such, there is a tremendous flux of gamma rays caused by neutron-capture events.

We do not want to build a gamma-ray detector; we want a 14-MeV neutron detector. Consequently, we used a medium-Z matrix to surround each scintillating fiber. The matrix (aluminum or black plastic) also stops Compton electrons produced by gamma rays from depositing all their energy in the scintillator, thereby reducing the gamma-pulse height relative to the desired neutron pulses (although at the cost of making more smaller pulses from the gamma rays). Compton electrons, which punch out through the sides of the fiber optics into the aluminum matrix, are stopped in the matrix. Consequently, if the detector electronics are designed to support a linear response over a wide dynamic range, then the large 14-MeV neutron pulses can be detected on a background of more numerous, but smaller, pulses from 2.5-MeV neutrons and gamma rays.

This detector scheme was first modeled with a Monte Carlo neutron and photon (MCNP) transport code[5] to determine the detector response and to help select optimal materials and geometry. It took only six months from the first prototype tests in October 1993 at EG&G Energy Measurements, Inc., Las Vegas, to the deployment of a 1,000-lb, four-channel system at the JT-60U tokamak in Naka, Japan. We used a large ^{60}Co source (30 kCi at 1 m) at EG&G Energy Measurements, Inc., to simulate the detector response to a nasty gamma-ray background, and we made energy-resolved neutron response measurements at the Los Alamos Ion Beam Facility (IBF) using a bunched DD neutron source with the tandem Van de Graaff accelerator. An example of the improved rejection of the hard gamma spectrum produced by neutrons in the IBF target and vicinity when using the composite fiber / aluminum matrix (instead of just the scintillator alone) is shown in Fig. 2. The ratio of 14-MeV neutron pulses to gammas at pulse height channel 200 is improved by 2 orders of magnitude, or more. This measurement was made possible by using beam bunching and time-of-flight electronic

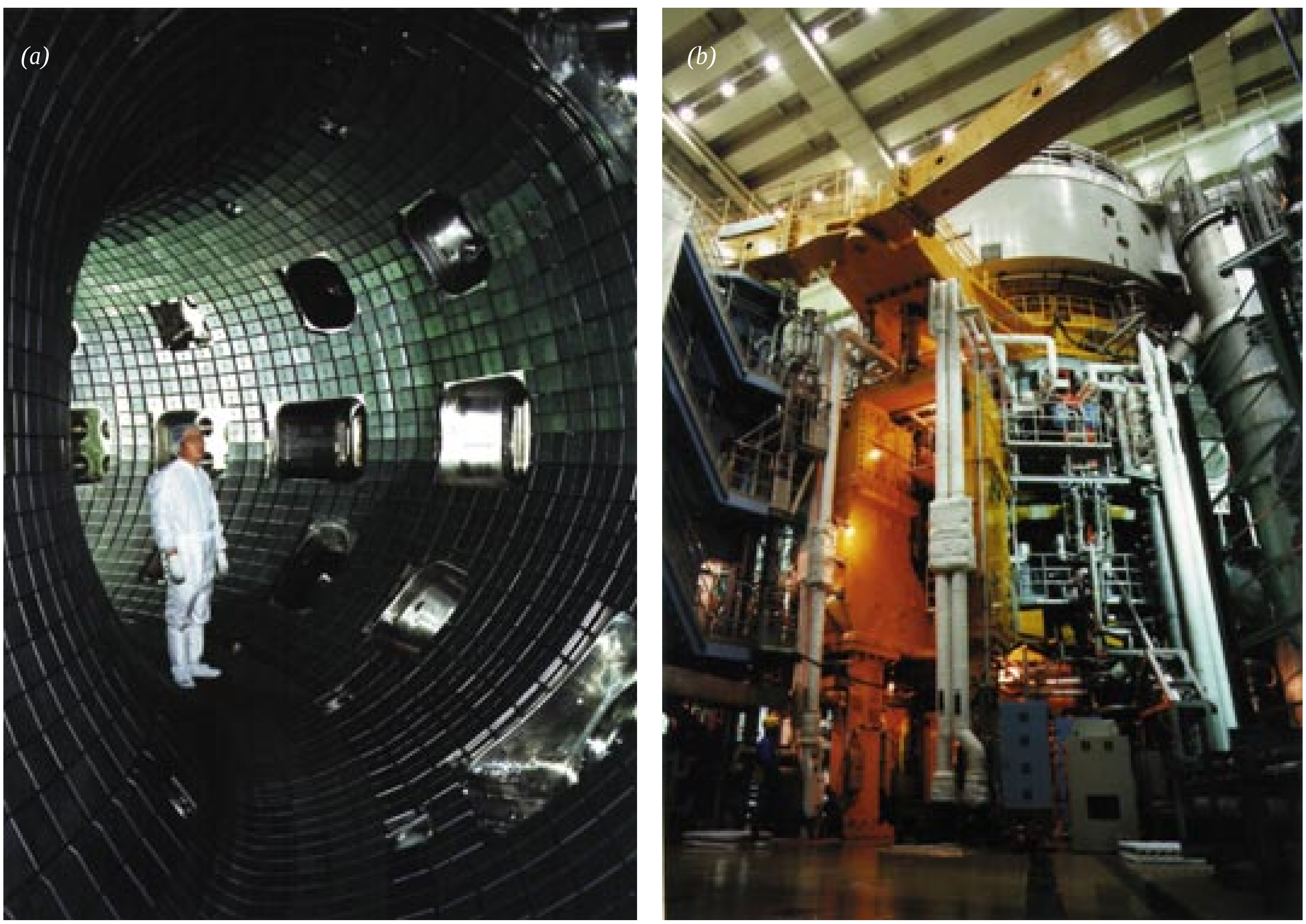
Fig. 2. Calibration of the scintillating-fiber neutron detector at the Los Alamos IBF using a tandem Van de Graaff accelerator. By setting a discriminator level in pulse-counting mode on channel 200 of the pulse-height analyzer, we detected mostly 14-MeV neutrons.



techniques, uniquely available at the IBF. We also characterized the angle response of the detector and the compact collimator system at the Princeton Plasma Physics Laboratory DT-neutron-generator radiation test range before we put a pair of detectors onto Princeton's DT-fueled Tokamak Fusion Test Reactor (TFTR).[6] Princeton's bare detectors were shown to have a 5:1 directional response to the 14-MeV neutron source at 0° and 90° orientations, with an FWHM (full-width at half-maximum) response angle of 30°.

To field our new diagnostic on a large tokamak, we needed a hot deuterium plasma in a machine with good confinement characteristics. Although we have collaborated at TFTR for a number of years, the TFTR experiment is already running with tritium fuel, and hence triton burn-up studies are no longer possible because of the presence of tritium. The Japanese JT-60U tokamak is the second largest tokamak in the world and is still running "deuterium-only" plasmas. Under auspices of the U.S./Japan Department of Energy International Collaboration Agreement on Fusion Energy, we began a joint effort at the Japan Atomic Energy Research Institute (JAERI) Naka site. Before this agreement, the Japanese had only time-integrated measurements of triton burnup via post-shot analyses of foils activated by the neutron emission from the tokamak. Dr. Nishitani had made some preliminary low-statistics measurements with a silicon detector in 1992, but this system was rendered unusable by neutron damage. Typical total DD neutron rates from JT-60U are 1 to 5×10^{16} neutrons/s for a few seconds during each 10- to 15-s plasma pulse. The DT neutron rate resulting from triton burnup is then expected to be about 100 times smaller than that of the DD neutron rate. Our

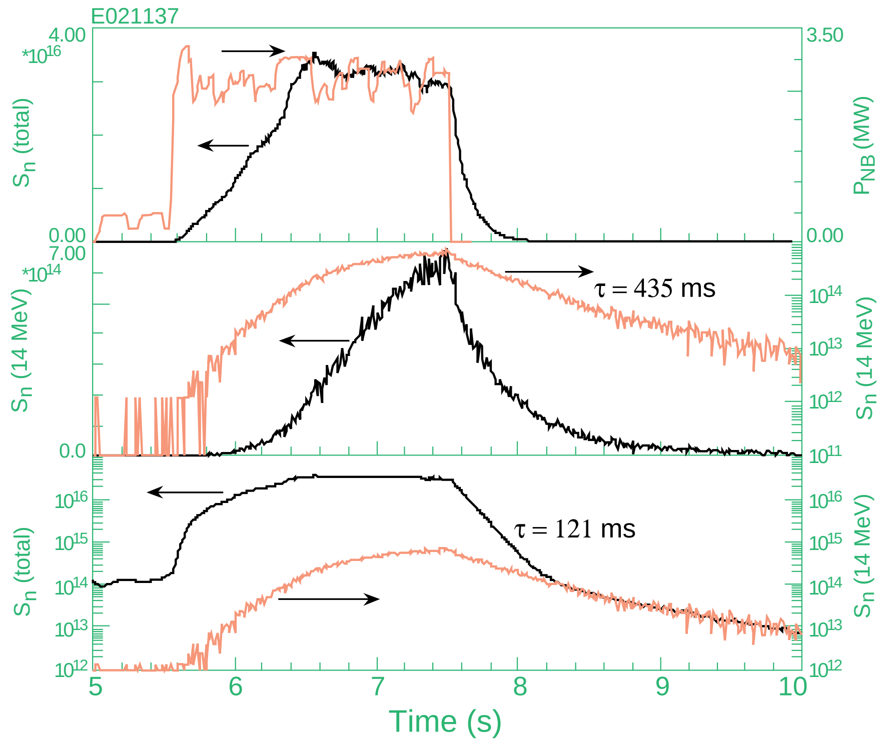
Fig. 3. Views of the JT-60U tokamak in Naka, Japan. Figure 3a shows an inside view of the JT-60U vessel. Figure 3b shows a side view of the JT-60U vessel.



system was positioned 2 m outside the 5-T toroidal field coils, about three stories from the ground near the tokamak. The size of the facility can be appreciated in Fig. 3.

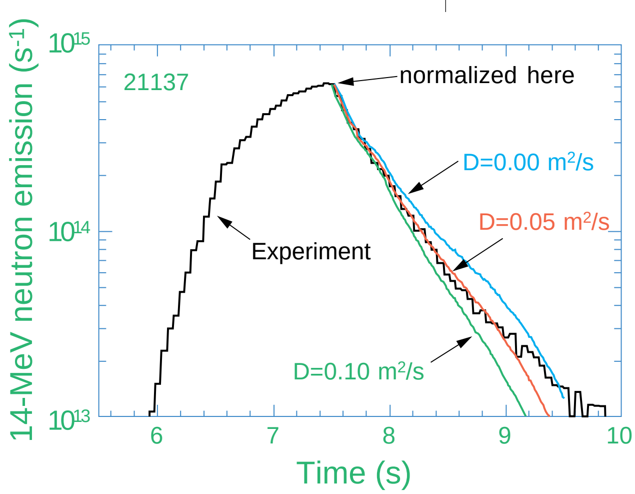
We have made time and spatially resolved triton-burn-up measurements on the JT-60U tokamak using a scintillating-fiber 14-MeV neutron detector system. Two chordal views have been operational since April 1994 with a 1-ms time resolution using 100-MHz counting electronics. DT-neutron counting rates of up to 400 kHz have been observed with the system, although the background rate resulting from DD neutrons is 20 MHz or higher. Cross calibration of the system to total neutron emission from a uranium-fission chamber and to shot-integrated DT yields measured by foil-activation techniques have been performed.

Fig. 4. *Data from a neutral-beam-heated plasma in JT-60U. A uranium fission chamber (total neutrons) is compared with the scintillating-fiber (14-MeV neutron) detector as a function of time in a 14-s plasma discharge [DT/DD = 0.02 at 7.5 s; (shot-integral DT)/(shot-integral DD) = 0.015].*



The peak DT neutron rate at the time that the 30-MW deuterium beams were turned off was as high as 2.5% of the total neutron rate, whereas the integrated triton burnup ranged from 0.4% to 1.9%. The detector has been used on the tokamak over an operating range of 1 x 10^{11} to 1 x 10^{15} DT neutrons / s. As the plasma cools down after the deuterium beams are shut-off, essentially only 14-MeV neutrons continue to be produced by the highly reactive tritons as compared with the 100-times smaller cross section for “cold” deuterons. These data are shown in Fig. 4 where the “total” and “DT” neutron rates come together after 8.4 s.

Fig. 5. *Time-dependent modeling of 14-MeV neutron emission from JT-60U for three different triton diffusion coefficients compared with an experimentally measured quantity. (The estimated diffusion coefficient for tritons is $D_T \approx 0.05$ m^2/s.)*



The data can be compared with codes to model the fractional burnup of the tritons. This comparison allows us to estimate the prompt and transport losses as the tritons slow down from their 1-MeV birth energy. When the tritons approach the peak in their reactivity at 120-keV energy, they will most likely fuse with the relatively cold (5- to 30-keV) background deuterium plasma. Because JT-60U has rather widely spaced toroidal field coils and hence a large magnetic-field “ripple” near the outside of the plasma, one can also obtain so-called “ripple-trapped-enhanced” losses of energetic ions, especially at a low-plasma current or large plasma diameters. Both of these effects are seen in our data.[7] Even for small, high-current plasmas, the tritons will diffuse out of the plasma. Figure 5 shows time-dependent code results (using 30 time slices per second of input data) that attempt to match the burnup of tritons as a function of time for three different triton diffusivities. For this plasma, the relatively small diffusion coefficient of 0.05 m^2/s matches the data rather well.

We are pursuing measurements with two chords and making plans to expand the system to an eight-chord array. Collaborations continue through data access over the internet, and personnel exchanges occur about once per year. In the meantime, we continue to look at triton burnup during a variety of plasma-operating scenarios, and we are planning to build a radiation-hardened version of this detector for applications on the International Thermonuclear Experimental Reactor (ITER) project.[8]

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MEGA: Search for the Rare Decay $\mu^+ \rightarrow e^+\gamma$

M. D. Cooper, M. Brooks, A. V. Chernyshev, G. W. Hart, G. E. Hogan, T. Kozlowski, M. A. Kroupa, V. D. Laptev, D. M. Lee, G. B. Mills, R. E. Mischke (P-25), F. J. Naivar, C. Pillai, J. C. Sturrock (AOT-6), S. C. Wright (University of Chicago), P. S Cooper (Fermi National Accelerator Laboratory), L. Tang (University of Hampton), M. Ahmed, Y. Chen, M. Dzemidzic, E. V. Hungerford III, K. Lan, B. W. Mayes II, L. Pinsky, W. von Witsch (University of Houston), K. Stantz, J. Szymanski (Indiana University), C. Gagliardi, F. Liu, R. E. Tribble, X. Tu, L. Van Ausdeln (Texas A&M University), D. D. Koetke, R. Manweiler, S. Stanislaus (Valparaiso University), B. Wright, K. O. H. Ziock (University of Virginia), D. Haim, L. E. Piilonen, Y. Zhang (Virginia Polytechnic Institute and State University)

The standard model of electroweak interactions has been successful in incorporating all experimental observations. In particular, family-number violating rare decays should be zero in agreement with their nonobservation to date. Yet most physicists believe that the standard model must be imbedded in a larger theory because of the number of unexplained constants it contains. Nearly all candidates for the larger theory predict that rare decays will proceed at rates close to the current limits. Hence, rare decays provide a sensitive method to search for physics beyond the standard model.

For a rare decay to be seen at measurable rates, the process must be mediated by a new particle that is virtually exchanged between leptons and / or quarks. The structure of the electroweak theory is simpler if the mass scale for these new particles is below 1 TeV. Current experiments that search for rare decays are sensitive in the mass range between 50 GeV and 1 TeV, which spans the gap between direct production experiments and the 1-TeV scale. The possibilities for a discovery of great importance are nonnegligible, and the puzzle of the origin of the family structure in the standard model is as topical as ever. In fact, two recent theories predict the observation of the process $\mu^+ \rightarrow e^+\gamma$ from the MEGA (**M**uon decays to an **E**lectron and a **GA**mma ray) experiment. The first is motivated by supersymmetry and connects the mixing in the super-partner sector to the CKM (Cabibbo-Kobayashi-Maskawa) matrix, whereas the other would explain CP (charge conjugation / parity transformation) violation in a superweak model as resulting from multiple Higgs doublets and produces $\mu^+ \rightarrow e^+\gamma$ as a consequence. The precise mass range in each model for each rare process is model dependent. Hence, all channels should be explored to obtain the model closest to the truth. The MEGA experiment searches for $\mu^+ \rightarrow e^+\gamma$ with a branching-ratio sensitivity (90% confidence) of 7 x 10^{-13}.

The construction of the MEGA experiment at Los Alamos is complete, and we are now obtaining data. MEGA takes advantage of the intense beams of surface muons available at the Los Alamos Meson Physics

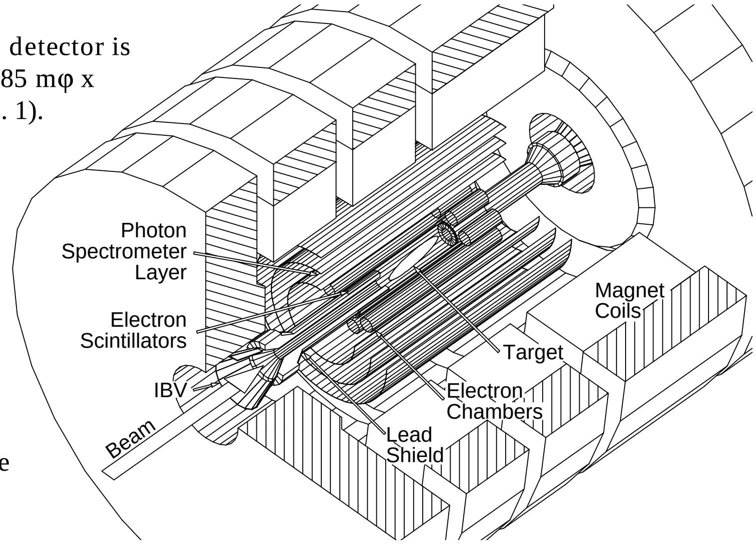


Fig. 1. A simplified cut-away view of the MEGA apparatus. The detector is mounted inside a superconducting solenoid with a 1.5-T field. The muons enter along the magnetic field and stop in the target. Positrons from muon decays are detected in the eight cylindrical wire chambers and the cylindrical arrays of scintillators surrounding the beam pipes. The three large cylinders are pair spectrometers for photon detection.

Facility (a 20-MHz average stop rate is used). The detector is contained in a large, warm-bore solenoid (1.5 T, 1.85 mφ x 2.9 m long) and consists of two spectrometers (Fig. 1). The first, a set of special, cylindrical proportional chambers, measures the kinematic properties of the decay electrons, and the other (the world's largest pair spectrometer) determines the same quantities for the photon. All of the charged particles arising from muon decay are confined by the magnetic field to the positron detector region; the photon counters are therefore in a relatively quiet environment. The signature for $\mu^+ \rightarrow e^+\gamma$ is a 52.8-MeV photon and a 52.8-MeV electron; these two particles, which originate at the same time from a common vertex, travel back to back toward the detector. The excellent resolution of the spectrometers at high rates allows any potential signal to be separated from backgrounds. Examples of the resolutions already achieved are 0.6 MeV for electrons and 1.5±0.3 MeV for photons of interest. Figure 2 shows the detector response to the muon-decay spectrum, and Fig. 3 shows the line reconstructed for a monoenergetic gamma ray from π^0 decay.

The positron arm consists of two parts: 174 scintillators that measure the positron arrival time and a set of multiwire proportional chambers (MWPCs) that are used to determine momentum. The MWPCs are cylindrical by design. One of the chambers has a 11.25-cm radius and surrounds the beam. The other seven of 6-cm radius are colinear and evenly spaced outside the larger chamber. The momentum component, which is perpendicular to the field, is measured by the wire hits, and the parallel component is measured from the induced pulses on the cathodes, which contain strips that spiral relative to the wires. These chambers have very stringent specifications. They have a normal thickness of 3 x 10^{-4} radiation lengths and consist only of inflated foils and wires; their shape is maintained by differential gas pressure. They operate at a 250-MHz instantaneous stop rate and draw up to 300 μA of beam-induced current without degradation of performance.

The photon arm is three concentric pair spectrometers of similar construction. Each pair spectrometer is made of lead converters, MWPCs, drift chambers, and scintillators. The inner two spectrometers have three drift chambers for tracking pairs, and the third one has a bigger turning region for the particles and an extra row of drift chamber wires to increase its acceptance for high-energy gamma rays. The increased capability of the third layer is extremely useful for determining the energy response function from the decay $\pi^0 \rightarrow \gamma\gamma$. If the π^0 is made from stopping pions via $\pi^- p \rightarrow \pi^0 n$, the energies of the two gamma rays range from 55 to 83 MeV. The measurement of track coordinates that are parallel to the axis of the cylinders is made by 1- by 180-cm-long delay-line strips with a time expansion of a factor of 40. The FWHM (full-width at half-maximum) resolution of these delay lines is around 0.8 cm over a length of 180 cm.

Data processing incorporates first- and second-level trigger modules that use programmable array logic encoded according to Monte Carlo simulations. The active multiplexing of FASTBUS channels depends on the geometrical output of the first-stage triggers and reduces the accidental backgrounds from low-energy photons to acceptable levels.

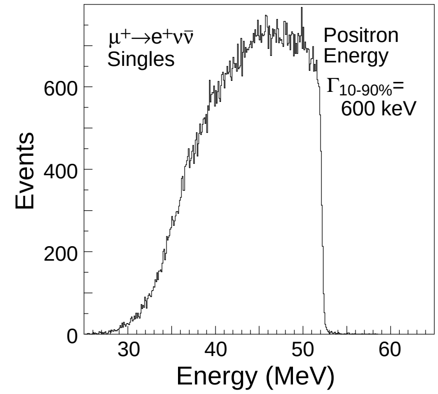


Fig. 2. The Michel spectrum of normal muon decay.

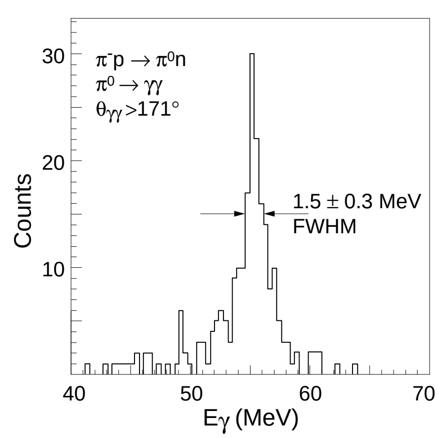


Fig. 3. A spectrum from $\pi^0 \rightarrow \gamma\gamma$ with the angle between the gamma rays greater than 171°. The π^0's are produced by stopping π^-'s in a CH_2 target.

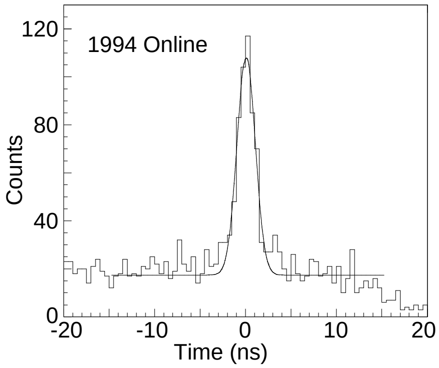


Fig. 4. The timing spectrum that indicates the presence of coincidences of positrons and photons from the expected process $\mu^+ \to e^+\gamma\nu\nu$.

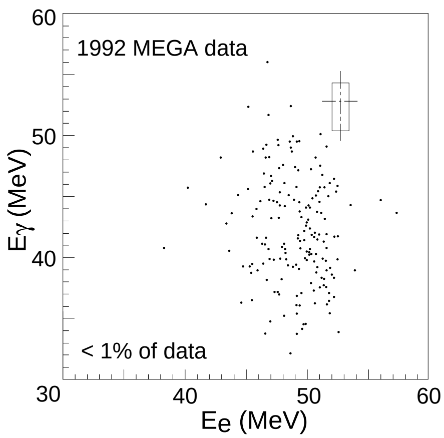


Fig. 5. The photon energy versus the positron energy for a set of events that are nearly back to back and in time. The empty box is where a potential $\mu^+ \to e^+\gamma$ signal should be.

Data and busy signals are routed in a trigger dependent way to a system of FASTBUS analog-to-digital converters, time-to-digital converters, and latches. The third-level trigger relies on the compute power of our eight-node farm of DECstation 5240s.

An essential feature of the on-line filter (*i.e.*, the third-level trigger) is to test for the synchronization of the signals from the two spectrometers. The only direct evidence of this synchronized timing is the observation of the allowed process $\mu^+ \to e^+\gamma\nu\nu$. The clear peak observed in Fig. 4 at a time difference of zero demonstrates that the timing is correctly prepared. The observation of the peak demonstrates that the apparatus can observe a real-coincidence process.

The first data to search for $\mu^+ \to e^+\gamma$ were taken in a 1992 engineering run with a partially completed detector and an average muon stop rate of 5×10^6 Hz. Figure 5 plots the photon energy versus the electron energy for a set of events that are nearly back to back and together in time. The empty box is where a potential $\mu^+ \to e^+\gamma$ signal should be. These data are less than 1% of the complete set and have a sensitivity of 5×10^{-10}.

The MEGA detector obtained production data during 1993 and 1994. The statistical power of the data represents an improvement factor of 42 over the current world limit on the branching ratio for $\mu^+ \to e^+\gamma$. During 1995, MEGA should collect enough new data to bring the cumulative sensitivity to 8×10^{-13}. The current data are being analyzed. There are two scenarios: (1) a signal of reasonable statistical significance has been observed, or (2) a new upper limit will be set. The first case is very exciting and would call for further investigation. The second case would likely signal the completion of the $\mu^+ \to e^+\gamma$ search with this apparatus.

The MEGA detector has exceptional specifications that allow it to perform other interesting measurements, such as improving the measurement accuracy of the Michel parameter ρ, which is a part of the formula for the muon decay rate as follows:

$$\frac{d\Gamma}{x^2 dx d(\cos\theta)} \sim 3(1-x) + \frac{2\rho}{3}(4x-3) \pm P_\mu \xi \cos\theta [1-x + \frac{2\delta}{3}(4x-3)],$$

where $x = E_e / E_{max}$ and θ is the angle between the e^+ direction and the muon spin.

The value of ρ is measured to be 0.7518 ± 0.0026. The standard model predicts 3/4. Deviations from the standard model value are often expressed in terms of the parameters of manifestly left/right symmetric models, where a right-handed intermediate vector boson is invented to eliminate parity violation at very high energies and to preserve it at low energies by being heavy compared with the left-handed one. The expected sensitivity of this new measurement will produce a limit on the mixing between the two bosons that is at least a factor 1.7 better than that known today.

If the target spot at the center of the MEGA positron spectrometer is both small and vertical, the energy acceptance of the apparatus is nearly uniform between 37 and 53 MeV for events that make more than one and less than two loops in their helix while in the detector. Using the high-rate capability of the MEGA data-acquisition system, we have collected

40 million events to measure the shape of the energy spectrum. The detector is designed to be symmetric upstream and downstream of the target. Because ρ is independent of the muon polarization, the sum of data from these two parts of the detector is used to remove polarization effects.

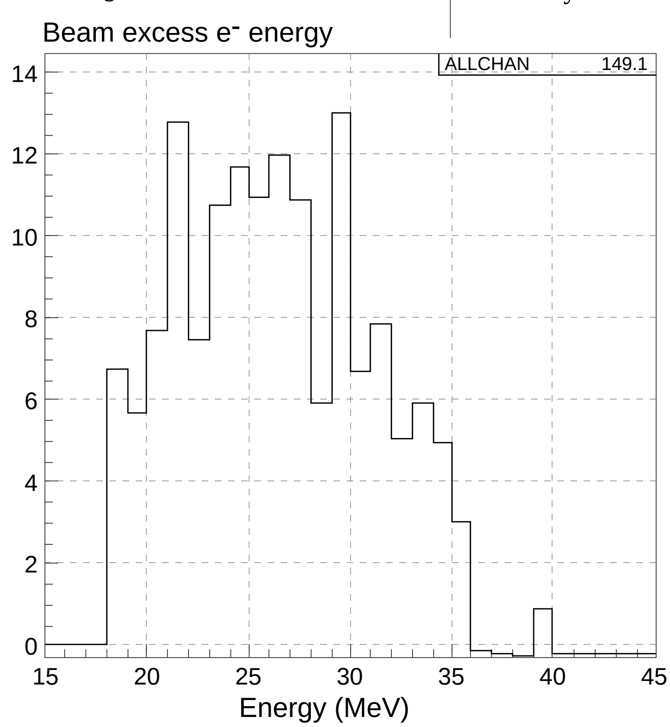
The data have a potential statistical precision of 0.0004, but systematic errors must be controlled. The data are broken into three sets to measure sensitivity to systematic errors. A surface muon tune provides the “standard” data set. For comparison, a spectrum produced with a reduced field checks the acceptance, and a beam tune using decay-in-flight muons with reversed polarizations verifies the symmetry of the detector. Qualitatively, the spectra behave as expected, but detailed Monte Carlo simulations are under way to see if the systematic errors can be made smaller than the statistical ones.

Liquid Scintillator Neutrino Detector

W. C. Louis [(505) 667-6723], D. H. White, F. J. Federspiel, V. D. Sandberg (P-25), R. D. Bolton (NIS-6), J. B. Donahue (AOT-7), G. T. Garvey (DSTBT), M. Schillaci (ESH-12), Collaborators from Brookhaven National Laboratory, the University of California at Riverside, the University of California at San Diego, the University of California at Santa Barbara, the University of California Intercampus Institute for Research at Particle Accelerators, Embry Riddle Aeronautical University, Linfield College, Louisiana State University, Louisiana Tech University, University of New Mexico, Southern University, and Temple University

The LSND (liquid scintillator neutrino detector) experiment has been designed and built to search concurrently for $\nu_\mu \rightarrow \nu_e$ and $\overline{\nu}_\mu \rightarrow \overline{\nu}_e$ oscillations with high sensitivity at the Los Alamos Meson Physics Facility. The observation of neutrino oscillations would have a profound impact on nuclear, particle, and astrophysics because it would imply that lepton number is not conserved and that neutrinos have mass and contribute substantially to the mass of the universe. In addition, the experiment will measure neutrino-proton elastic scattering and thereby determine $G_1^s = \Delta s$, the strange quark contribution to the proton spin. At low Q^2 the neutrino-proton elastic-scattering cross section is approximately proportional to $G_1^2 = (-0.63 + G_1^s/2)^2$, so that a cross-section measurement directly determines G_1^s unambiguously without additional assumptions. The LSND experiment was completed during the summer of 1993; data were obtained for a total of five months of high-intensity beam during the 1993 and 1994 running periods. The integrated number of protons on the A6 target during this interval corresponded to over 7,800 C, and the detector was live for over 95% of the time that the beam was on.

Fig. 1. The observed electron energy distribution from ν_e C -> e^- N scattering.



The detector consists of a tank with 200 tons of dilute liquid scintillator with 1,220 photomultiplier tubes (8 in. each) that are mounted on the inside tank and cover 25% of the surface. Both Cerenkov light and scintillation light are detected. The tank resides inside the existing E645 veto shield, and the experiment makes use of the present A6 beam-stop neutrino source. Several upgrades were made to the detector before the 1994 running cycle. First, all of the front-end QT boards were modified to obtain a more linear pulse-height response and to increase the dynamic range. Second, the old hand-wired trigger boards were replaced by printed-circuit boards, and the trigger software code was modified to decrease the trigger dead time. In addition, a problem in the data-acquisition system that caused runs to die after a few hours was fixed. Finally, additional veto scintillators were installed below the veto shield to tag cosmic muons that entered the detector horizontally. All of these upgrades performed quite well during the 1994 run.

The detector performance has been verified by the observation of the well-known reactions $\nu_e\ {}^{12}C \rightarrow e^-\ {}^{12}N_{gs}$, $\nu_e \rightarrow \nu_e$, and $\nu_\mu\ {}^{12}\mathrm{C} \rightarrow \mu^-\ {}^{12}N_{gs}$. The first reaction has a well-known cross section because of its relation to ${}^{12}N$ beta decay. Figure 1 shows the observed electron energy distribution, which agrees well with the predicted shape and validates our estimated ν_e flux from μ^+ decay at rest. The neutrino flux has been calculated[1] from measured pion production rates and from a simulation of the target region shown in Fig. 2; the estimated systematic uncertainty of the flux is 7%. The electron angular distribution for all events with a single electron is shown in Fig. 3; θ is the angle of the electron relative to the incident neutrino direction. The excess of events near cos $\theta = 1$ is due to the second reaction and agrees with the predicted rate and angular resolution. The third reaction can be identified by observing the produced muon and the resulting decay electron. The time and distance between the muon and electron, shown in Figs. 4a and 4b, reflect the expected μ^- lifetime and the expected position resolution of ~ 30 cm for each particle in the detector. Figure 5 plots the particle

Fig. 2. A schematic of the target region where neutrinos are produced.

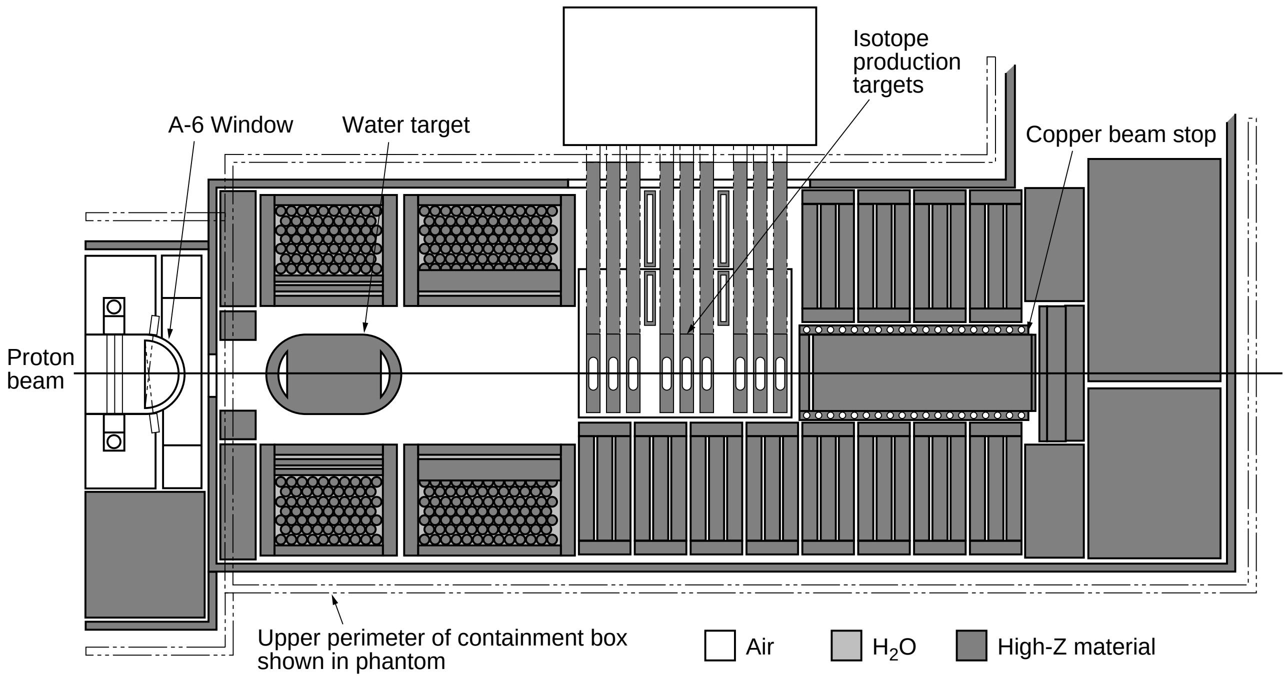
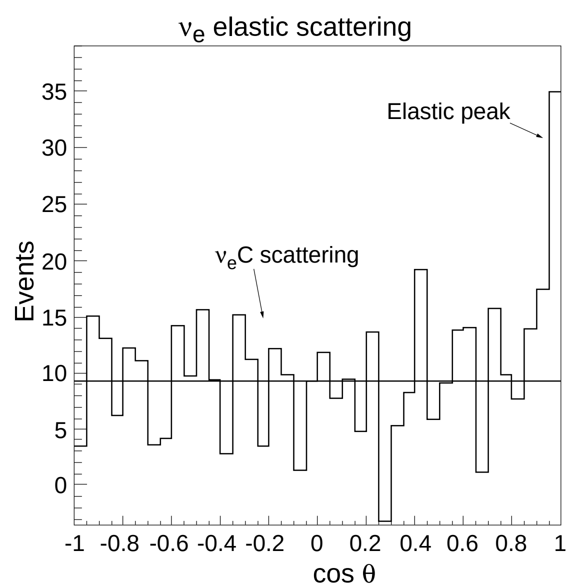


Fig. 3. The electron angular distribution for all events with a single electron.



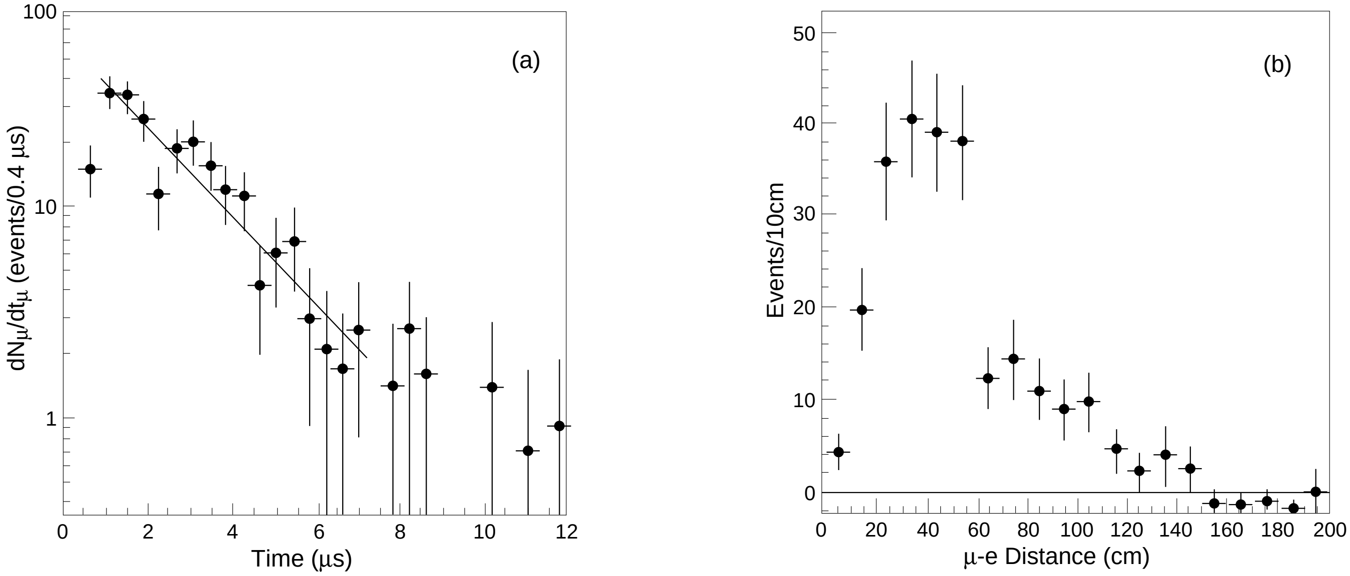


Fig. 4. Distributions from $\nu_\mu C \to \mu^- N$ scattering. Figure 4a shows the time between the muon and the decay electron. Figure 4b shows the distance between the muon and the decay electron.

identification parameter for both the muon and electron. The particle identification parameter depends on the fit to the Cerenkov ring and the time distribution of the produced light. Figure 5 shows good muon-electron separation. Finally, Fig. 6 shows the observed charge resulting from the muon in the detector. The shape of the charge spectrum agrees well with the Fermi Gas Model[2] (*i.e.*, the solid histogram); however, the measured cross section[3] is 3 times lower than the Fermi Gas Model prediction and 2.5 times lower than a continuum random phase approximation (RPA) calculation.[4] Our measurement of $\nu_\mu C$ scattering is interesting in its own right and may have relevance to experiments that use the Fermi Gas Model at low energies.

A potentially more exciting result is the observation of an excess of events in the search for $\bar{\nu}_\mu \to \bar{\nu}_e$ oscillations via the reaction $\bar{\nu}_e p \to e^+ n$. Figure 7 shows the electron energy spectrum with the beam-off background subtracted. Also shown is the expected background resulting from known neutrino interactions. A clear excess of events is observed in

Fig. 5. The particle identification parameter for both the muon and the decay electron.

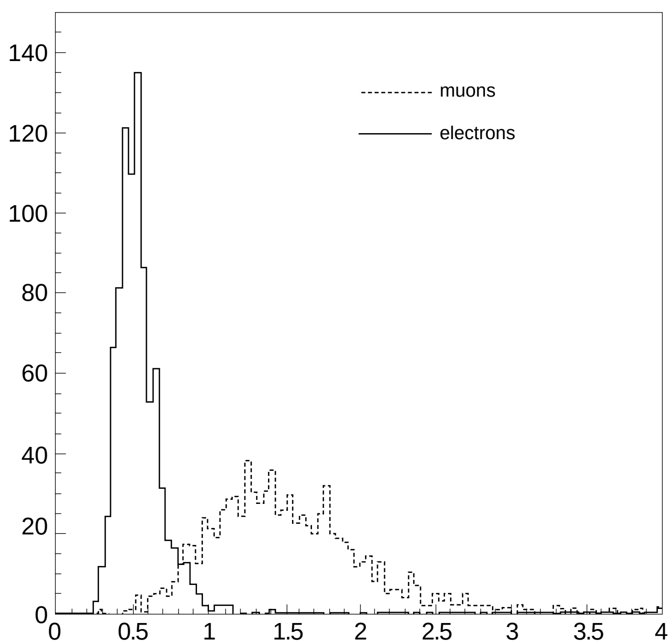
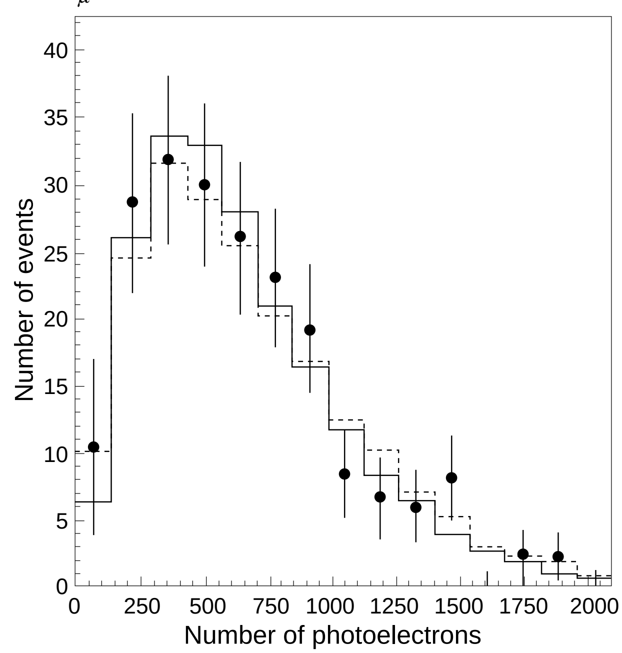


Fig. 6. The observed charge resulting from the muon from $\nu_\mu C \to \mu^- N$ scattering.



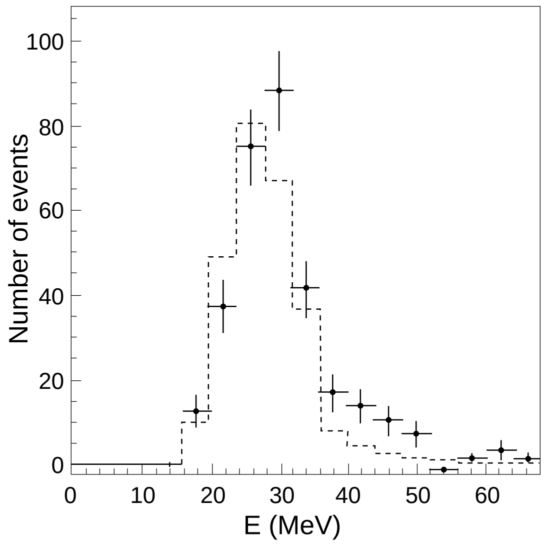


Fig. 7. The electron energy spectrum with the beam-off background subtracted. Also shown is the expected background resulting from known neutrino interactions.

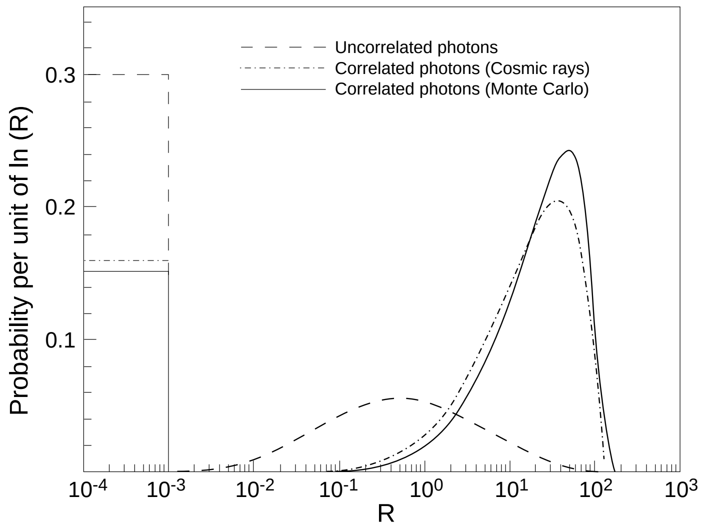
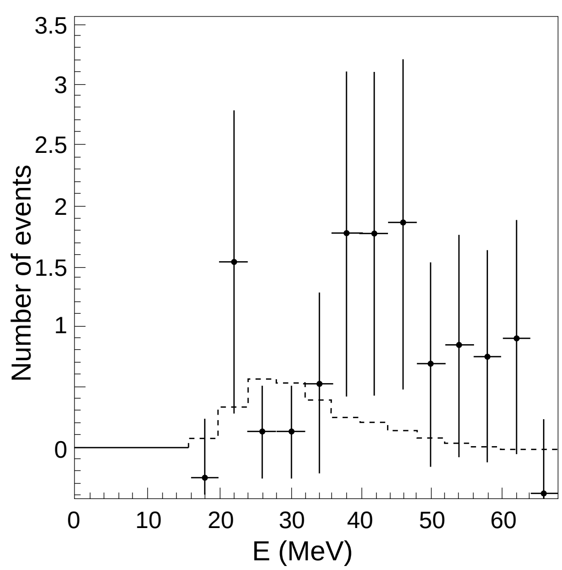


Fig. 8. The likelihood ratio (R) distributions for correlated and accidental photons.

the 36- to 60-MeV energy range. The recoil neutron can be observed by looking for a correlated 2.2-MeV γ produced by the reaction $np \rightarrow d\gamma$. To determine whether a γ is a correlated 2.2-MeV γ or an accidental γ, a likelihood ratio R is defined, where R is the likelihood that the γ is correlated divided by the likelihood that the γ is accidental. The R distributions as shown in Fig. 8 are quite different for the correlated γ and the accidental γ. Figure 9 shows the electron energy spectrum with the beam-off background subtracted and with an associated γ that has R > 30. The excess of events in the 36- to 60-MeV energy range is consistent with neutrino oscillations with an oscillation probability of ~ 0.5%.

More data taking is planned for the experiment, and the performance of the detector is under continuous study. Both of these efforts are expected to improve our understanding of the phenomena described in this article.

Fig. 9. The electron energy spectrum with the beam-off background subtracted and with an associated photon that has R>30.



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Atomic Parity Nonconservation Experiment

D. Tupa, V. D. Sandberg (P-25), R. Guckert, D. J. Vieira, J. M. Wouters (CST-11), D. Preston (University of Colorado)

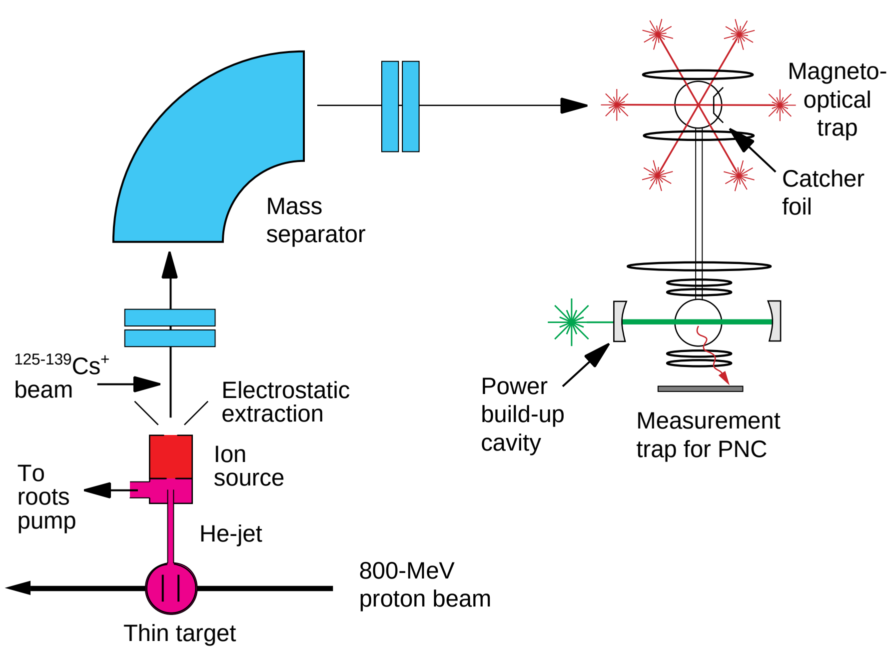
The atomic parity nonconservation (PNC) experiment, a measurement of the interference of the weak and electromagnetic amplitudes in a series of cesium isotopes, will provide a precise test of the minimal standard model (MSM). Furthermore, the weak amplitude determined in this type of measurement is particularly sensitive to isospin-conserving radiative corrections; therefore, the PNC experiment is uniquely sensitive to certain types of physics extensions beyond the MSM.[1] This sensitivity is made possible by measuring the PNC component of the atomic cesium 6s→7s transition in a series of cesium isotopes. Comparing the PNC signal from a wide range of isotopes allows us to eliminate the uncertainty of the results from theoretical calculations in atomic structure, the largest component of uncertainty in present measurements, so that a test of the MSM to the level of 0.2% can be performed.

Because all but one cesium isotope are radioactive, our experiment involves the production of cesium radioisotopes, the selection and accumulation of a sufficient quantity of radioisotopes, and the measurement of the atomic PNC signal. Figure 1 is a schematic of our proposed experiment. A helium-jet target creates cesium isotopes by fission and spallation reactions when placed in a medium-energy proton accelerator such as the Los Alamos Meson Physics Facility (LAMPF). The cesium isotopes are transported to a mass separator, where particular isotopes are selected, accumulated, and then implanted in a foil. The foil is periodically heated to release the collected cesium as atoms, which are cooled, confined by laser beams in an optical trap, and then transferred to the apparatus where the actual PNC measurement takes place.

Over the last two years, the cesium PNC collaboration, which consists of researchers from P Division, CST Division, and the University of Colorado, has made significant strides toward the long-term goal of the project. Our colleagues at the University of Colorado have measured the PNC signal in stable ^{133}Cs,[2] are currently perfecting a high-precision PNC measurement technique, and have built an efficient optical trap for capturing cesium.[3]

At Los Alamos, we have built and tested a helium-jet target in the high-intensity proton beam at LAMPF. We measured collection rates of cesium isotopes ranging from ^{127}Cs to ^{142}Cs on the order of 10^7 to 10^8 atoms/s/isotope. This water-cooled, thin-target system operates reliably even at the highest proton beam intensity of 700 μA with no loss in yields at high intensity. We are therefore confident

Fig. 1. A diagram of the atomic PNC experiment.



that we can create the isotopes we need in sufficient quantity for the atomic PNC experiment.

We have constructed an optical-trap test stand to investigate the problems of efficiently trapping cesium atoms. A magneto-optical trap uses laser beams to slow the atoms down and to trap them within a small volume. Figure 2 shows a diagram of the laser beams. The frequency of the laser light must be monochromatic and stable to better than one part in 10^8. To meet this requirement, we have built a saturated-absorption frequency standard and diode lasers with a frequency feedback system; we then locked the lasers to the standard. We have successfully trapped the stable isotope of cesium. Figure 3 is a photograph of the trap, which consists of six laser beams that intersect in a glass vacuum cell. Two magnetic-field coils encircle the glass cell; the fluorescing cloud of trapped cesium atoms is visible in the center.

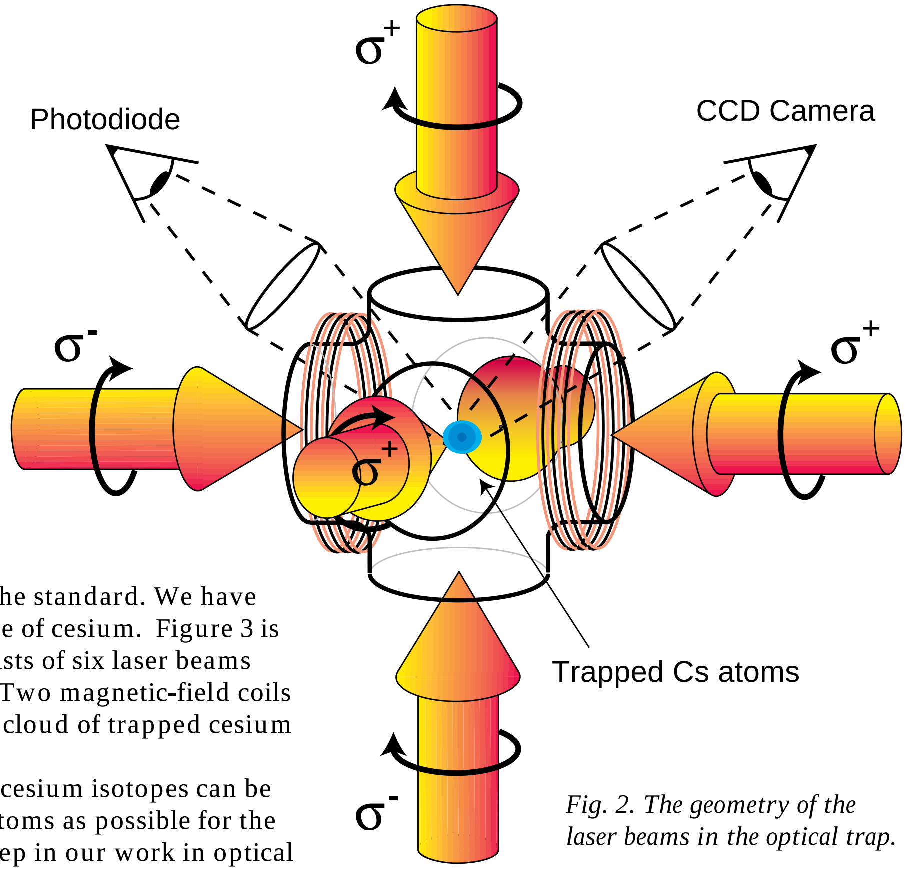


Fig. 2. The geometry of the laser beams in the optical trap.

Because only a limited quantity of cesium isotopes can be produced, we must gather as many atoms as possible for the PNC measurement. Thus, the next step in our work in optical trapping is to build a high-efficiency trap. For this, we have installed a high-intensity Ti:Sapphire laser for trapping the atoms; it produces 50 times the power of the laser diodes. The cell design and magnetic-field geometry have been optimized for high efficiency. A problem with efficiently trapping thermal atoms is that only a small percentage can be decelerated and trapped by the laser beams. The remainder pass through the beams and stick to the walls of the cell. A special nonstick dry-film coating, which will prevent the atoms from adhering to the walls of the cell, will allow us to trap each individual atom.

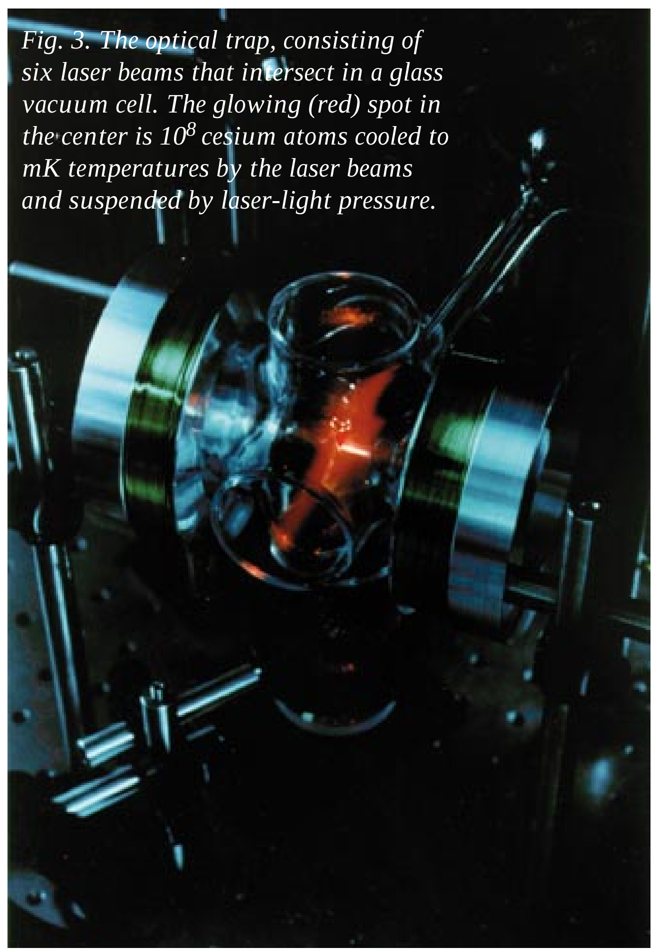


Fig. 3. The optical trap, consisting of six laser beams that intersect in a glass vacuum cell. The glowing (red) spot in the center is 10^8 cesium atoms cooled to mK temperatures by the laser beams and suspended by laser-light pressure.

We are currently beginning studies to improve the efficiency of the optical trap. An optical trap will be mounted on a refurbished mass separator so that we can trap radioactive species. This experimental setup will allow us to develop and test several key technologies for the experiment (*i.e.*, implanting a particular isotope on a foil in an optical-trap cell, flash heating the foil to release the atoms into the cell, shifting the frequency of the lasers to trap the desired radioisotope, and efficiently gathering a large percentage of the atoms in a trap).

In the last few years, we have made great progress toward performing this challenging experiment. We have demonstrated a helium-jet target that produces different cesium radioisotopes, established an optical-trap test stand, and are currently building a very efficient cesium trap. Finally, we are recommissioning a mass separator, which will be integrated with an optical trap so that radioactive species can be confined.

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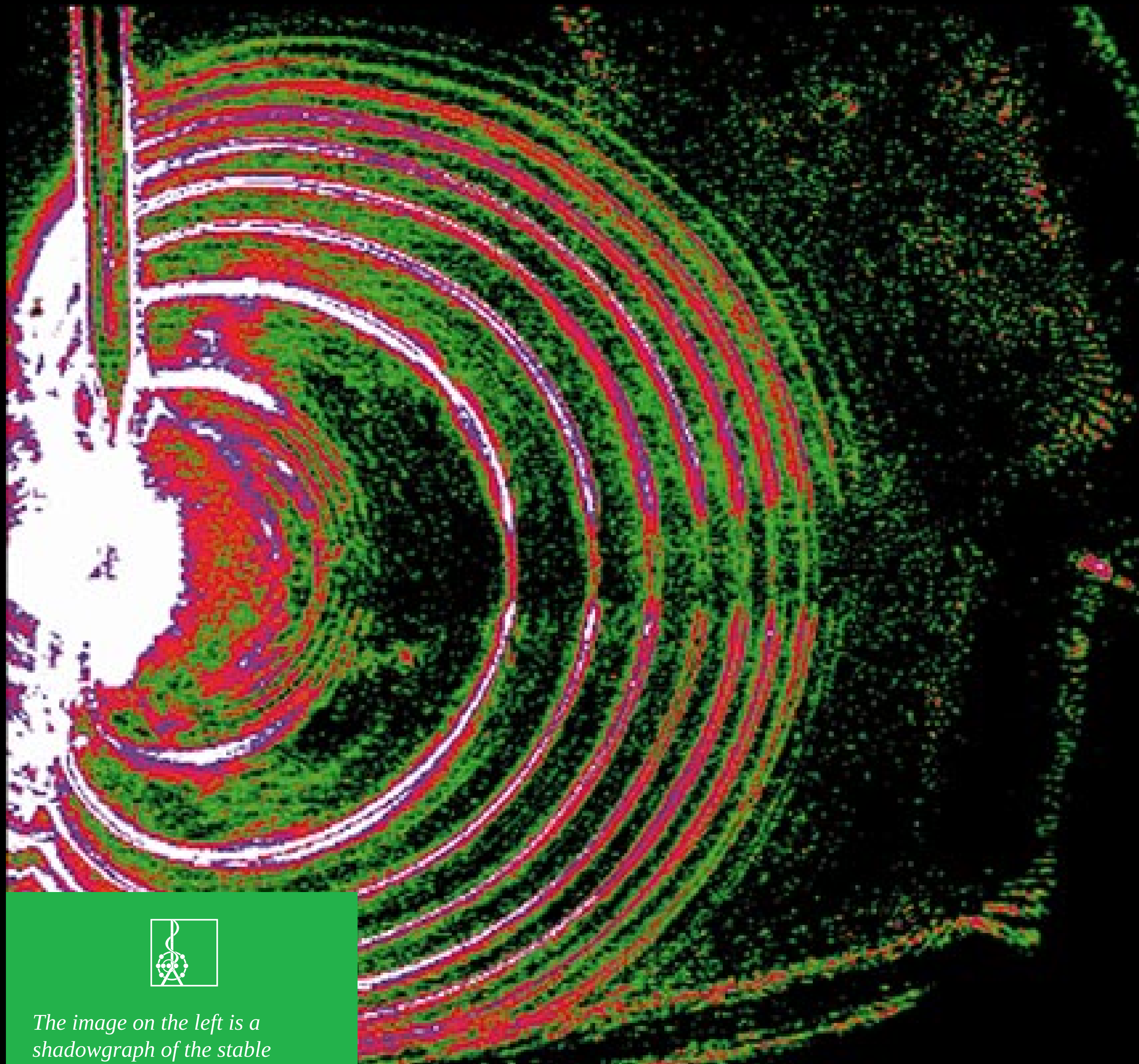
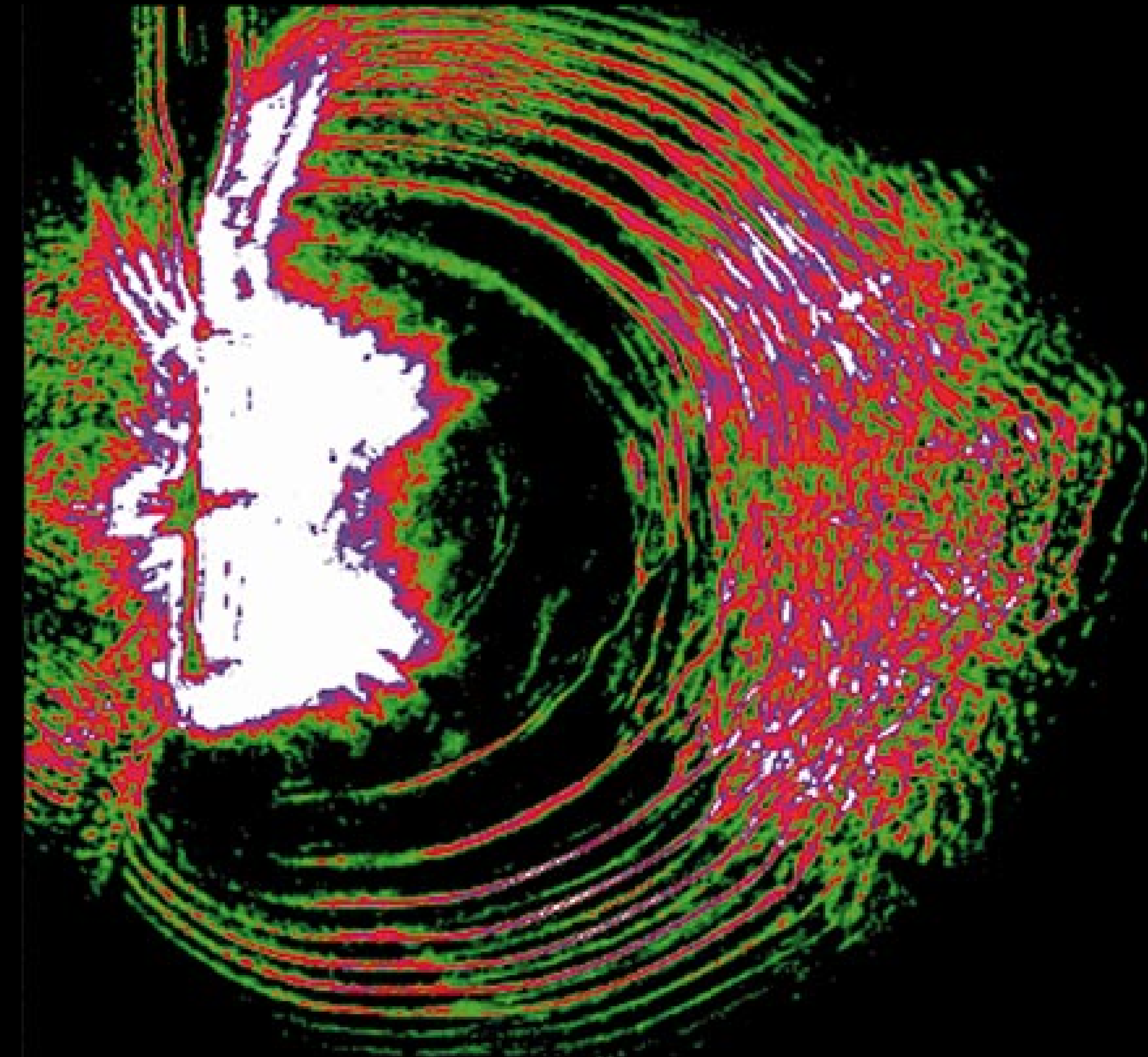
Chapter Three *Project Descriptions*





The image on the left is a shadowgraph of the stable propagation of a blast wave in helium, whereas the image on the right shows an unstable blast-wave propagation in xenon. This research involves investigations of the propagation of Taylor-Sedov blast waves.

P-21: Biophysics

Electrophoretic Velocities of Single Molecules

A. Castro [(505) 665-8044], M. V. Peters, E. B. Shera (P-21)

We have developed a technique for the electrophoretic separation and identification of single molecules. The electrophoretic velocities of individual molecules in solution under an applied electric field are measured. Single molecules are subsequently identified by comparing them with the electrophoretic velocity characteristic of a particular molecular species. An electric field applied between the ends of a capillary cell causes the molecules to migrate. The individual molecules are detected as they pass through each of two laser beams. The electrophoretic velocity is then calculated from the time required for each molecule to travel the distance between the two beams. The technique has been successfully demonstrated for the identification of nucleic acids and proteins. The single-molecule sensitivity of the technique is many orders of magnitude greater than that of conventional methods. The technique represents an enormous step in the effort for enhancing the sensitivity of analytical instruments, and it promises to bring a new array of capabilities to many areas of science and technology, from biochemical analysis of clinical samples to the detection of trace environmental contaminants.

Magnetoencephalography Sensor Program

E. R. Flynn [(505) 667-4746], R. H. Kraus, Jr., P. F. Ruminer, R. C. Garcia (P-21)

The magnetoencephalography (MEG) program is funded by the Department of Energy (DOE) Office of Health and Environmental Research, the National Institutes of Health, and a DOE cooperative research and development agreement (CRADA). The principal thrust has been the design, construction, and testing of a large full-head MEG system for the human brain. During the past period, the dewar design was completed and is now being fabricated through a contract with Conductus, Inc. This company is also producing the first 50 SQUIDs (**S**uperconducting **QU**antum **I**nterference **D**evices), which have been designed in a collaborative program. Finite element calculations were performed to ensure adequate safety and stress relief for the bottom of this dewar, which is designed to fit a normal human head. The SQUID electronics have been modified to incorporate new technology involving digital-signal processing (DSP) chips for direct computer control. An HP747i computer with a VME crate was obtained to control the SQUID electronics, program the DSPs, and provide a data-acquisition platform. The DSP system has been tested, and several publications have been issued. Calculations of the expected system performance were also carried out and published.

Magnetocardiography: Sensors and Analysis

E. R. Flynn [(505) 667-4746], R. H. Kraus, P. F. Ruminer, Jr., R. C. Garcia (P-21), J. C. Mosher (ESA-MT)

As part of a CRADA to develop new instruments for weak-field applications, a twelve-sensor system for measuring magneto-cardiography (MCG) fields and other applications is being developed. Initial measurements were made on a prototype system. These measurements led to the design of a new dewar that will contain a twelve-sensor array using the Los Alamos imaging-surface concept. The major parts of this dewar have been constructed and tested for vacuum and cryogenic stress. A low-field chamber was constructed from alternating layers of Mumetal and aluminum cylinders to test this, and similar, sensor systems. This chamber reduces external fields by several orders of magnitude and permits exact measurements of field strengths from a well-defined source array. The original measurements revealed an unexpected sensitivity of the SQUIDs to electrostatic fields, and therefore precautions have been taken to avoid future damage to the SQUIDs. In preparation for future measurements, an extensive analysis of fetal MCG data obtained in collaboration with Strathclyde University in Scotland has been carried out with advanced signal-processing techniques. A manuscript on this analysis has been prepared.

Construction of a Weak-Field Sensor Facility
E. R. Flynn [(505) 667-4746], R. H. Kraus, P. F. Ruminer, Jr., R. C. Garcia (P-21), X. D. Wu (STC), D. W. Reagor (MST-11)

The facilities and resources of the weak-field sensor program in MEG and MCG have been extended to develop a weak-field sensor facility using both low- and high-temperature superconductors. This effort has been augmented by the award of Laboratory-Directed Research and Development / Competency Development funding for this mission. During this period, proposals for extending the mission of the facility into nondestructive evaluation and gravity-gradiometer measurements have been formulated. In particular, sensors for sensitive-corrosion detection have been proposed. The use of DSP techniques for the SQUID electronics has opened up a number of new possibilities for using these sensor systems in more hostile environments, as well as for novel situations like gravity gradiometry. Several of these applications have patent implications that are being explored for future CRADA collaborations. The effort is being closely coordinated with new developments from the Materials Science and Technology / Superconducting Technology Center on high-temperature SQUIDs where joint testing of these devices using the P-21 facilities has been carried out. A sensor based on high-temperature superconducting materials and SQUIDs is currently under design with plans for testing at our facility in the near future.

Magnetic Resonance Imaging: Analysis and Head Modeling
D. M. Ranken [(505) 665-2550], J. S. George (P-21)

Anatomical magnetic-resonance-imaging (MRI) head data are used with MEG to correlate brain structure and function, provide constraints for MEG inverse-fitting procedures, and provide realistic conductor models for MEG forward calculations. The software package MRIVIEW was developed using Research System’s IDL language to support P-21’s MEG research program. It provides tools for viewing MRI data in two and three dimensions, mapping MEG source locations onto MRI data, and segmenting head anatomy. Recent modifications include the conversion of MRIVIEW to a widget-based system, improvements to the segmentation procedures, and the development of an interactive three-dimensional viewer, which provides several methods for combining and viewing brain functional and anatomical information. Segmented MRI data are used to obtain accurate head models, which include mesh representations of the inner skull, outer skull, and head surfaces. The current method for obtaining these meshes is to shrink wrap icosahedral-based meshes onto the appropriate segmented objects in MRI data. A volume-based, generalized Delaunay-tetrahedralization method, which is currently being developed, can provide surface meshes, as well as space-filling meshes. Surface meshes are now being used in a boundary element method for obtaining MEG forward solutions using the **L**os **A**lamos **He**ad **M**odel (LAHEM) computer code. Space-filling meshes will be needed for planned finite-difference and finite-element approaches to the MEG forward problem.

Data Acquisition with an Object-Oriented Software Bus

A. F. McGirt, Jr. [(505) 667-5005] (P-21), Collaborator from the University of Washington

The current techniques of object-oriented software development provide a methodology to develop a set of data-acquisition and -analysis software tools according to a common specification in a manner that is analogous to the way computer hardware has been developed since the advent of bus structures for minicomputers and microcomputers. This approach, called the object-oriented software bus (OOSB), allows one to write independent object-oriented-programming-based software objects that correspond directly to hardware objects, data-acquisition tasks, and data-analysis tools. Software objects have been written for numerous CAMAC-, GPIB-, and VME-based hardware modules. These software objects can then be used in acquisition-task objects to meet a specific experiment's requirements. This OOSB model has been used successfully in numerous small laboratory-scale data-acquisition systems and in several large projects as well. A sample of those projects includes a neutron beta-decay coincidence experiment, an adaptive-processing and fuzzy-logic support system, and a remote-counting system for the Sudbury Neutrino Observatory neutral-current detectors. Current work is directed toward providing a general object-based development system, which will be available on several platforms, including Macintosh, Power PC, Windows, and Sun.

Biomorphic Systems

M. W. Tilden [(505) 667-2902], J. D. Moses (P-21)

Animals have adapted well to an enormous number of different environments, and the control systems that have evolved to accomplish these adaptations are a rich source of ideas for the design of man-made devices. We are beginning to build machines that use these ideas in something approaching biologically realistic form. The key to this capability is the emerging understanding of neural systems. The nervous systems of vertebrates are incredibly complex—the human brain contains approximately 10^{12} neurons connected by roughly 10^{15} synapses. No hope of anything approaching a complete understanding of such a system exists for the foreseeable future, nor of building anything remotely as complex. Even a single neuron is an impressive computing machine, typically receiving about 1,000 synaptic inputs from other neurons and synapsing onto 1,000 others. In spite of this complexity, VLSI emulators of large but orderly neural systems, like the retina, have been built. By contrast, the nervous systems of invertebrates are much simpler. The medicinal leech does quite well with only about 10^4 neurons, and the fly has roughly 3×10^5. This relative simplicity has allowed a number of specialized invertebrate neural circuits typically comprising around ten neurons to be isolated and studied in detail. Among the best understood are several central-pattern-generator (CPG) circuits that are responsible for repetitive motions such as walking, swimming, and chewing. Beyond design details, this work tells us that simple neural circuits are very effective for certain tasks, including the control of animal locomotion. The goals of this project are to explore simple biologically inspired systems for a variety of applications with the idea that more complex systems might follow. We have shown that a capable "walker" (*i.e.*, a walking robot) can be controlled by a ring of six or fewer artificial neurons, functionally emulating a biological CPG. We are trying to use this technology in other systems, specifically to stabilize satellites in a simple and computer-free way and to build better sensory systems for robots. We hope to extend this work by developing more biologically realistic, but still simple, systems (*e.g.*, by using more realistic "neurons" and neural circuits) and to find practical applications for the technology.

Light-Sensitive Proteins
B. M. Willardson [(505) 667-2735], T. Yoshida, J. F. Wilkins, G. J. Jensen, B. D. Thornton, M. W. Bitensky (P-21)

This program investigates enzymes that enable the brain to convert the event of photon capture into visual pixels. These enzymes are contained in an elongated cylinder that is on top of a specialized nerve cell called a rod, which is embedded in the retinal nerve net. In rods, a single quantum can be detected, and rods are able to regulate their sensitivity over a dynamic range of 3 orders of magnitude. When the dynamic range of rods and cones is added, we learn that the human eye can function over photon flux densities that vary by 6 log units. We study the mechanism by which the rods can regulate their sensitivity to light. One principal regulator of rod sensitivity is the protein phosducin. Phosducin can sequester subunits of the G-protein transducin, and it thereby determines availability of this protein. G-proteins are key participants in signal amplification. Phospho-phosducin is incapable of sequestering G-proteins. When it is unphosphorylated, phosducin can readily bind to and sequester G-proteins. There is clearly a need to integrate phosducin function into the light cycle of the rod so that phosducin is quiescent under dark conditions when all of the G-proteins are required for signal amplification. Moreover, phosducin needs to be more active during increases in photon flux density to limit the degree of signal amplification. We have found that the light-sensitive regulator of phosducin activity is the calcium ion, which is elevated in the dark and falls following illumination. Calcium can activate a rod-outer-segment-specific enzyme. The product of this enzyme, cyclic AMP, promotes phosphorylation of phosducin. Thus, in the dark, phosducin is inactivated, and the rod can use its entire G-protein pool for the purposes of signal amplification. The opposite conditions apply following illumination. Calcium ion concentration falls, the adenylyl cyclase becomes inactive, and the pathway that phosphorylates the protein phosducin becomes inactive. Thus, in the light, phosducin is able to constrain G-protein function.

Prolongation of Storage of Human Blood
T. Yoshida [(505) 665-2553], B. M. Willardson, M. Esterl, B. D. Thornton, G. J. Jensen, C. Jones, E. Rutland, M. W. Bitensky (P-21), S. K. Wilson (P-22)

The focus of our program is on the liquid preservation of blood with the ultimate goal of storing human red blood cells for 20 weeks. This innovation would allow patients to serve as their own blood donors (autologous transfusion) for preplanned surgeries. It would also enhance the logistics for blood collection and utilization (heterologous transfusion), thereby expanding the nation's blood supply. Both applications are extremely important in the defense and civilian arenas. The problem of blood stabilization simplifies into the task of ensuring that during the period of refrigerated storage the metabolic and structural integrity of the red cell is maintained. For example, conversion of red cells to an echinocyte or prickly form results from ATP (adenosine triphosphate—a high-energy nucleotide used to establish ion gradients) depletion. In the echinocyte state, red cells lose membrane surface area by budding membrane vesicles from the spicules. Reduced surface / volume ratio compromises the ability of red cells to traverse capillaries, resulting in their removal from the circulation. Thus, adequate ATP levels must be maintained. In addition, the membrane bilayer and cytoskeleton of red cells is readily compromised by hemoglobin breakdown products that arise during storage. The appearance of these products must be prevented both by hemoglobin stabilization and the prevention of a reduction in the entropic force of water that accompanies storage at 4°C. Current efforts are aimed at both hemoglobin stabilization and the quantitation and prevention of protein unfolding, which results from storage under conditions that diminish the hydrophobic force of water.

P-22: Hydrodynamic and X-ray Physics

Final State Effects and Correlation in Atomic and Molecular Systems
R. J. Bartlett [(505) 667-5923], D. V. Morgan (P-22)

The one-electron model is widely used in many areas of physics because of its calculational simplicity. However, the model does not faithfully reproduce phenomena such as multiple ionization caused by electron-electron interactions. We are studying phenomena that are caused by electron correlation and many-body processes to determine the limits of the one-electron model and the strength of electron-electron interactions. To test recent theories that incorporate the electron-electron interactions, we have measured the double ionization of helium at photon energies well above the ionization threshold. We have also measured the multiple ionization of argon and neon near the K-edges in these materials using the Los Alamos soft x-ray synchrotron radiation source and a time-of-flight ion-state spectrometer. For helium, the measured ratio approaches an asymptotic value of ~ 1.6% (close to the predicted value) near 2.8 keV but falls below this value for energies above ~ 3.8 keV. We attribute this decrease in the ratio to an increase in the single ionization caused by ionizing Compton scattering [J. A. R. Samson, Z. X. He, R. J. Bartlett, and M. Sagurton, "Direct Measurement of He^+ Ions Produced by Compton Scattering Between 2.5 and 5.5 keV," *Physics Review Letters* **72**, 3329 (1994)] and [J. A. R. Samson, C. H. Greene, and R. J. Bartlett, "Measurement of the Ratio of Double to Single Photoionization of Helium at 2.8 keV Using Synchrotron Radiation," *Physics Review Letters* **71**, 201 (1994)]. In our recent measurements, we have separated the Compton ionization from that of photoionization to allow for a true test of calculations involving both ionizing Compton scattering and the many-body perturbation theory. These results are significant because they reveal an ionization channel that has not been considered in past measurements. Compton ionization may also be important whenever the photoionization cross section is small. The neon and argon results also show multiple ionization, as well as Auger decay and post-collision interactions.

The GeoNet Electronic Bulletin Board
C. M. Briles [(505) 665-1198] (P-22)

The goal of the GeoNet electronic bulletin board (BBS) is to broaden students' interest in, and understanding of, science and mathematics by making them participants in the science process. The bulletin board electronically connects New Mexico science classrooms with one another and with scientists at Los Alamos National Laboratory. This communication link provides a platform for discussions on scientific topics and an infrastructure for schools to participate in Laboratory science programs and experiments. In addition, the BBS is a resource bank for exemplary math and science resources, references, and software applications. Using the bulletin board, students and teachers network with experts in scientific fields by reading and responding to "forums" written by Los Alamos scientists. The forums discuss topics in science and mathematics. In addition, experiments that can be conducted in the classroom to investigate these topics are suggested. Teachers and students upload the results of these investigations to public segments of the bulletin board where the data can be examined and downloaded by other school sites. General questions are also discussed on the BBS. The contents of the bulletin board are applicable to all science and mathematics teachers and their students, particularly those at the middle-school level or above.

Pegasus II Pulsed Power Facility

J. C. Cochrane [(505) 667-1227], J. S. Shlachter (P-22)

Pegasus II is a high-energy facility used to perform a variety of weapons-physics and pulsed-power experiments. The facility consists of 144 energy-storage capacitors arranged as a two-stage Marx bank with a peak, erect voltage of 100 kV. The 4.3-MJ stored energy for this voltage makes Pegasus II one of the largest capacitor-bank facilities in the world. Pegasus II is used to produce peak currents as high as 12 MA in cylindrical inductive loads and can be operated either with or without a fast opening switch. In addition to its role in conducting plasma- and hydrodynamic-physics experiments, the Pegasus II Facility continues to address technological issues of developing an efficient switch. During 1994, shots were fired approximately every two weeks. Several different experimental campaigns involved both heavy solid liners and thin aluminum foils. These targets become plasmas during an implosion. The solid-liner experiments, which were in support of the nuclear-weapons program, addressed hydrodynamic issues of relevance to weapons designers. The foil-implosion experiments were used to stagnate the plasma on axis of the cylindrical system and convert the kinetic energy to thermal energy and radiation.

A Debris-Free, Electron-Beam-Driven Lithography Source at 130 Å

R. D. Fulton [(505) 667-2652] (P-22), D. C. Nguyen (CST-5), J. M. Kinross-Wright, S. H. Kong (AOT-9), J. C. Goldstein, M. E. Jones (X-1), J. Abdallah, D. P. Kilcrease (T-4)

Most of the proposed extreme ultraviolet lithography (EUVL) sources use the interaction of some high-energy density source (*i.e.*, a laser, an electron beam, or an arc discharge) with a solid target. Extreme ultraviolet radiation can be efficiently generated by these techniques, but debris from the interaction region impacting on the reflective optics can substantially degrade the performance of the optical projection system. Los Alamos and Grumman Corporation are cooperatively investigating a debris-free source for EUVL. This source uses the predicted anomalous energy loss of a short-pulse electron beam in a preformed plasma to heat and ionize the ions to a charge state whereby efficient radiation near 130 Å occurs. Accelerators developed for the free-electron laser program at Los Alamos are used as the electron-bunch source. A laser-driven photocathode is used to produce a series of 15-ps electron bunches each containing 4 nC of charge with an energy of 15.5 MeV. The weakly ionized preformed plasma is created by purely classical ionization processes resulting from the initial few electron micropulses within the accelerating radio-frequency (rf) macropulse. When a critical electron density is reached, the plasma responds collectively to the electron micropulse, and a large-amplitude plasma wave is generated. The plasma wave efficiently slows the high-energy electron beam while heating the background plasma electrons. The initial electron population rapidly heats and then equilibrates with the bulk ion and electron populations. With neon as the dominant ionic species, an efficient filamentary radiator of line radiation near 130 Å is created. We have demonstrated the anomalous energy-loss process in a recent experiment. An energy loss of 2.5% was observed in a 10-cm-long gas cell filled with 200 mtorr of argon. Classically, a radiation length of hundreds of kilometers can be calculated for argon at these pressures. We have therefore observed a greater than 10^5 enhancement of the stopping power. Future experiments will extend this work to shorter pulses whereby even larger enhancements are expected.

DARHT Diagnostics

R. D. Fulton [(505) 667-2652], P. J. Rodriguez (P-22), B. Papatheofanis (NIS-12), D. Moir (DX-11), Collaborators from EG&G Energy Measurements, Inc.

The Integrated Test Stand (ITS), is the technical precursor to the Dual-Axis Radiographic Hydrotest (DARHT) Facility. It uses the same technology so that operational expertise may be developed. Critical issues related to DARHT's performance can be addressed, and advanced beam diagnostics can be developed and debugged. P-22 is developing a number of diagnostics that will measure the energy distribution and focusing ability of the electron beam. The focused spot size is a figure of merit for the usefulness of DARHT as a radiographic source. A 60° magnetic spectrometer currently under construction will measure the energy distribution of the electron beam. The detector within the spectrometer consists of a thin sapphire plate that emits Cerenkov radiation when struck by the electron beam. A fast-optical streak camera records the light emission allowing the temporal history of the electron energy to be determined with 1% energy resolution and subnanosecond temporal resolution. The energy distribution determines the focusing ability of the magnetic lenses, which bring the beam to its final focus. The effective focal length is determined by the energy so that a beam with a broad energy distribution is smeared out into a large spot—a phenomena equivalent to chromatic aberration in visible optics. Two other complementary diagnostics under development will determine the unfocused beam size without physically intercepting the beam. The beam size determines the effective f/# of the magnetic lens and hence determines the focusing properties. The first diagnostic, which is currently in use, consists of a magnetic pick-up loop, which measures the diamagnetic field produced by the propagating beam. Under certain assumptions about the rotational equilibrium and spatial distribution of the beam, this diagnostic provides a measure of the diameter. The second diagnostic provides a check of this measurement, free of assumptions concerning the beam's rotational equilibrium and spatial distribution. It consists of a 24-GHz interferometer designed to measure the transverse line integral of the electron density. Combined with an independent measurement of the total current, this diagnostic determines the average beam diameter.

Heated-X-ray Fluorescer Studies

G. C. Idzorek [(505) 667-8848] (P-22), W. Matuska (X-5)

Fluorescent-yield experiments are being performed using the Pegasus II pulsed-power machine. A detector, shielded from an extremely intense x-ray source to prevent its instant destruction, allows us to observe fluorescent x-rays that are emitted from a fluorescer foil illuminated by the x-ray source. The ionization of the fluorescer foil during the experiment may cause changes in the fluorescent yield of the foil and, consequently, in the system-response calibration of the fluorescer/detector combination. Because of the vastly different temperature and intensity outputs between Pegasus II and events at the Nevada Test Site (NTS) substantial changes have been made to the detector design for the experiment. The signal-to-noise ratio is maximized by mounting the x-ray detector perpendicular to the fluorescer foil, which is oriented at 30° to the incident x-ray beam. This arrangement eliminates noise from specular reflection and minimizes the number of scattered photons. In addition, the detector photocathodes are coated with cesium iodide to maximize quantum efficiency. Exposure to the atmosphere degrades the cesium iodide; therefore, the whole arrangement is mounted in a vacuum enclosure inside the Pegasus II vacuum chamber. When the chamber is evacuated, a remote-controlled enclosure door opens to allow the detector to view the Pegasus II x-ray source. Preliminary experimental data show that a fluorescent signal is detectable; data analysis continues to determine if the signal-to-noise ratio is adequate to observe fluorescent-yield changes.

Pegasus Pulsed-Power Experiments

G. C. Idzorek [(505) 667-8848], R. J. Bartlett (P-22)

We are fielding a number of x-ray diagnostics on the Los Alamos Pegasus II machine. A new time-integrated, seven-image, filtered-x-ray pinhole camera provides spatial information about x-ray production from the implosion between 60 eV to several keV. Filtered x-ray diode (XRD) detector arrays provide time-resolved x-ray output for several different x-ray energies from 6 eV to 10 keV. A transmission grating spectrometer (TGS) provides time and spectrally resolved data from 60 eV to 2 keV with a 5-ns time resolution. We fielded the pinhole camera, the TGS, fifteen radial-view XRDs, eight axial-view XRDs, and three fluorescer experiments as x-ray diagnostics on the most recent Pegasus II shot. The data are currently being correlated to study the uniformity and output of the x-ray source. The results are being used to benchmark the implosion calculation codes, observe effects of machine modifications, and determine the suitability of the x-ray source for experimental programs.

Procyon Pulsed-Power Experiments

G. C. Idzorek [(505) 667-8848] (P-22)

We are fielding filtered XRD detector arrays that provide time-resolved x-ray output at several different x-ray energies from 6 eV to 10 keV on the Procyon explosive-driven pulsed-power experiments. Our standard detector arrangement for future shots will probably consist of two sets of radial-view seven-channel XRDs and one set of axial-view four-channel XRDs. The data are currently being correlated to study the uniformity and output of the x-ray source. The results are being used to benchmark the implosion calculation codes, observe effects of machine modifications, and determine the suitability of the x-ray source for experimental programs.

Russian Collaborations

G. C. Idzorek [(505) 667-8848], R. J. Bartlett (P-22), R. G. Hockaday (P-24), Collaborators from EG&G Energy Measurements, Inc.

Major collaborations continue with Russian scientists from the Arzamas-16 and Angara-5 laboratories. An experiment involving Los Alamos, Sandia National Laboratories, Lawrence Livermore National Laboratory, and Russian scientists from the Triniti Laboratory, Troitsk, Russia, was performed early this summer at the Sandia Saturn Facility. The experiment was a follow-on to experiments performed on the Angara-5 machine at the Russian laboratory. Los Alamos fielded a TGS to provide time and spectrally resolved information about imploding cylindrical liners from a series of shots, which were performed in May and June 1994. The TGS system provided data from 60 eV to 2 keV with a 1-ns time resolution. Data analysis from these shots continues. Complementary diagnostic systems were also fielded as a joint effort between Los Alamos, Sandia National Laboratories, Lawrence Livermore National Laboratory, and the Russian laboratory. A second collaboration involving the explosive-driven pulsed-power system, MAGO II, is a joint experiment between Los Alamos National Laboratory and Arzamas-16. We are fielding soft x-ray diagnostics to observe the pinch plasma. Because the MAGO chambers operate with a few torr of D-T gas, photocathode-type biased detectors cannot be used. Instead, thin, dead-layer silicon photodiodes were selected as the detectors most suitable for observing the pinch plasma.

X-ray Detector Calibration Program
G. C. Idzorek [(505) 667-8848] (P-22), R. G. Hockaday (P-24), Collaborators from EG&G Energy Measurements, Inc.

Group P-24 has several vacuum-ultraviolet and x-ray beamlines at the National Synchrotron Light Source (NSLS) located at Brookhaven National Laboratory. These beamlines provide monochromatic photon beams between about 30 eV to 20 keV. EG&G staff members are stationed at NSLS to support our detector-calibration program, which provides calibrated detectors that are used for x-ray measurements of experiments on the Los Alamos Pegasus II and Procyon pulsed-power machines, the Sandia National Laboratories Saturn pulsed-power machine, the Lawrence Livermore National Laboratory Nova laser, Russian collaborations, and other facilities. The EG&G team maintains a set of calibration standards that cover the range from vacuum-ultraviolet energies to 50-keV photon energies. Specialized hardware and software allows the team to calibrate our normal diagnostic detectors at NSLS. The detectors and a calibration report are then returned to Los Alamos. About 100 of the normal calibrated detectors have been used on Athena programs this past year. For unique detector configurations, the EG&G team provides their expertise and equipment to assist scientists in their calibrations.

X-ray Detector Design
G. C. Idzorek [(505) 667-8848], S. C. LaMarra (P-22), R. G. Hockaday (P-24)

Several new designs for x-ray detectors are being developed to support the Athena program. The XRD-96 design uses an aluminum photocathode enclosed in a filter-mounting cylinder mounted onto a vacuum-tight TNC bulkhead connector. The entire XRD-96 assembly is about the size of a thumb. This small size allows a number of detectors with different filters to be mounted in a compact array, which provides spectral information from Pegasus II and Procyon implosions. Approximately 100 XRD-96 detectors have been produced by EG&G Energy Measurement, Inc.; calibrated at our Brookhaven National Laboratory synchrotron x-ray beamlines; and expended on Pegasus II and Procyon. Silicon photodiodes are also being studied for use in diagnostics where either a flat-detector response (*i.e.*, bolometers), partial-vacuum operation such as the Russian MAGO experiments, a tiny size (< 1 mm square), or relative insensitivity to surface contamination is desirable. The P-24 Electronics Section possesses the expertise to mount and wire bound the tiny detectors into different configurations. Infinitely thin x-ray filters can be used because filters may be evaporated directly onto the diode surface, and so they need not be self-supporting. A number of mounted diodes have been purchased for the MAGO experiments, and we are considering purchasing a large quantity of unmounted diode chips. To avoid difficulties with the electrical-to-fiber-optic signal conversion that is required by the electrical-isolation needs of the Pegasus II and Procyon machines, we are exploring scintillator-coated fiber-optic detectors to directly convert x-ray signals to light, which can then be recorded on a streak-camera system. If successful, this technique will have the advantages of the silicon photodiodes, and the need for expensive optic transmitters, receivers, and digitizers will be eliminated.

Electromagnetic Probing
R. E. Kelly [(505) 667-6492] (P-22)

A feasibility study has been initiated to investigate the possibility of probing metallic containers for the presence or absence of a layered system that consists of conductors with different conductivities and permeabilities. An optimum probing frequency, which has been derived, depends upon both geometry and electrical constants; typical values are in the low kilohertz region and below. Because a low frequency is needed for penetration, the highly attenuated transmission field is a diffraction pattern. Efforts are currently concentrated toward a method of detecting permeability variations.

Electromagnetic Pulses from a Chemical Explosion Originating in a Tunnel
R. E. Kelly [(505) 667-6492] (P-22)

Electromagnetic pulses generated by a chemical explosion deep within a tunnel have been detected by sensors placed on both sides of the tunnel’s portal. These detectors consisted of antennas, current transformers, B-dots, and D-dots. The main objective was to collect data for nonproliferation studies complementary to, and in conjunction with, seismic methods. The electric field strength at the portal computed from the data was on the order of 50 mV/m. A Fourier transform indicated that most of the energy occurred below about 3 MHz. Several of the sensors displayed periodic sharp spikes probably not related to the device. Surface-guided waves were detected along power and ground cables and along the railroad track. Time-dependent surface current and charge were measured on the portal door, which serves as a secondary source for external radiation.

Explosion-Generated Electromagnetic Wave Propagation
R. E. Kelly [(505) 667-6492] (P-22)

Calculations have been made to study the propagation characteristics of a signal through a portion of Earth. The signal was due to an underground explosion. The results show a large frequency-dependent attenuation and considerable dispersion, mainly below 10 MHz, with a square root of frequency dependence for the phase velocity. Duct propagation, similar to that experienced in the atmosphere, in the manner of a leaky waveguide is possible.

Elastic-Backscattering Lidar for a Miniature Seeker Technology Integration Satellite

T. W. Meyer [(505) 667-3467] (PD-DoD), W. T. Buttler, D. A. Clark (P-22), D. M. Alde, P. Dyer (P-23), J. L. Banger (AOT-5), W. B. Cottingame (NIS-2), K. M. Grace (NIS-4), J. L. Longmire (NIS-4), G. J. Nunz (NIS-RD), C. R. Quick, Jr. (CST-1), R. S. Reid (ESA-EPE), W. W. Saylor (NIS-4), J. R. Stephens (CST-1), V. K. Viswanathan, J. J. Tiee (CST-6), B. Wong-Swanson (NIS-4)

An elastic-backscattering lidar (**Li**ght **D**etection **A**nd **R**anging) system is being designed for the Ballistic Missile Defense Organization. The lidar will be flown on a miniature seeker technology integration (MSTI) satellite in low-Earth orbit. The 100-kg payload features a 76-cm-diam, primary-light-collection mirror and a diode-pumped Nd:YAG laser (1,064 nm) that emits 1.5 J per pulse at a repetition frequency of 50 Hz. The telescope, which is fixed with respect to the satellite, has a 6° field-of-regard, within which a scanning mirror will select the laser-beam direction and the field-of-view of 0.5 mrad. Other payload elements are the detector (avalanche photodiode) and the R3081-microprocessor-based payload control electronics. The lidar will track a theater missile from space by measuring a succession of passive, active-exhaust-plume, and active-hard-body signals. It will generate a track file that can be transmitted to a kinetic-kill vehicle. Presently, however, there are very few measurements of the backscattering properties of missile exhausts. Therefore, we deployed a ground-based lidar system at the White Sands Missile Range to track and measure the exhaust plume from an Aries missile launch at a range of 7 km. Measurements were made at 1.06- and 0.53-μm wavelengths simultaneously. The Aries volume backscatter coefficient at 1.06 μm was 0.015 m^{-1} sr^{-1}. The Aries exhaust can easily be observed from space using the MSTI lidar parameters. Furthermore, the calculated backscatter coefficient for the Aries plume is in the range of 0.0021 to 0.013 m^{-1} sr^{-1}, depending on the phase of the aluminum oxide from the rocket and the size distribution of the particles. In addition to missile tracking, we will demonstrate the lidar's dual-use potential for ecological monitoring from space.

Atlas

W. M. Parsons [(505) 667-7872], C. Thompson, R. J. Kasik, W. B. Hinckley, R. F. Gribble (P-22), W. A. Reass, F. J. Wysocki, E. E. Robinson (P-24), D. W. Bowman, J. R. Griego (DX-17), R. L. Bowers, D. L. Peterson, H. Lee (X-5)

Atlas, a proposed $43 million line-item construction project, is designed to be a key facility for weapon-physics experiments and a center for high energy-density physics experiments to strengthen the national science and technology base. Atlas will use z-pinch techniques, similar to Pegasus II, for both hydrodynamic and radiation experiments. For hydrodynamic experiments, Atlas will achieve pressures greater than 30 Mbar in cm^3 volumes. For radiation experiments, it will produce greater than 1 MJ of ~100-eV x-rays without the use of an opening switch. The target driver is a 36-MJ array of 600-kV Marx modules. These modules will deliver a peak current of 20 to 25 MA in 2 to 3 μs. The modules can be charged in 40 ms using the Los Alamos 1430-MVA generator and a 50-MJ set of intermediate energy storage inductors. Atlas will include full experimental-support facilities, including a darkroom, a target-assembly area, shielded diagnostic enclosures, a data-analysis center, and a coordination and planning center. Construction will be completed by late FY99. Activities in 1994 were centered on physics scaling, component development, and prototype design and testing. These activities will validate the experimental performance of Atlas and help establish the technologies required to effectively move into the formal design process in FY96. These efforts will continue into 1995 and include the design and certification of major components, the establishment of the insulation and charging schemes for the capacitor bank, and the construction and testing of a Marx-module prototype.

Joint United States/Russian Plasma-Formation Experiments for Magnetized Target Fusion

J. S. Shlachter [(505) 665-1888], B. G. Anderson, J. W. Canada, P. Rodriguez, R. C. Smith, L. R. Veeser, G. Idzorek, D. W. Scudder, O. F. Garcia (P-22), I. R. Lindemuth, P. T. Sheehey (X-1), R. E. Reinovsky (DX-DO), J. M. Christian, C. E. Findley, J. H. Goforth, H. Oona (DX-15), R. C. Haight, N. S. P. King, G. L. Morgan (P-23), R. E. Chrien (P-24), S. M. Younger (CISA), C. A. Ekdahl, Jr. (PDNW), R. Kirkpatrick (NIS-9), G. L. Stradling (PDDoD), Collaborators from EG&G Energy Measurements, Inc., and the All-Russian Scientific Research Institute of Experimental Physics, Arzamas-16, Russia

The quest to achieve controlled thermonuclear fusion has evolved into two mainline approaches: magnetic fusion energy (MFE) as embodied in tokamaks and inertial confinement fusion (ICF). Approximately 10 orders of magnitude in density, pressure, and time scales separate each approach from the other. Although both MFE and ICF have made steady progress toward ignition, actual demonstration of ignition requires the building of at least one additional generation of new machines. Intermediate between MFE and ICF in time and density scales is an area of research known in Russia as “magnitnoye obzhatiye” (MAGO) and in the U.S. as magnetized target fusion (MTF). MAGO / MTF uses a magnetic field and a preheated, wall-confined plasma within a fusion target. The magnetic field suppresses thermal-conduction losses in the fuel during the target implosion and the hydrodynamic-compression-heating process. The high initial adiabat of the preheated, magnetized fuel makes it possible to reach ignition temperatures at modest convergence ratios. Although the basic principle of MAGO / MTF was recognized in the 1940s by Fermi at Los Alamos and at approximately the same time by Sakharov in the former Soviet Union, MAGO / MTF has not been extensively pursued in the U.S. MAGO / MTF includes, but is not limited to, some previously reported concepts in imploding-liner fusion and impact fusion and includes the electron-beam-driven “phi” targets. Analysis performed at Los Alamos and the All-Russian Scientific Research Institute of Experimental Physics (VNIIEF) at Arzamas-16 in Russia suggest that ignition may be more readily achieved in the MAGO / MTF than in either MFE or ICF. Furthermore, the existence of VNIIEF explosively driven pulsed-power sources, which can provide currents and energies in excess of 200 MA and 200 MJ, respectively, means that ignition experiments in MAGO / MTF may be attempted without the major capital investment required in the more conventional approaches. A MAGO / MTF system requires two elements: (a) a preheated, magnetized, wall-confined plasma within a fusion target and (b) a target-implosion system. In April 1994 at Arzamas-16 and in October 1994 at Los Alamos, Los Alamos and VNIIEF performed a series of experiments aimed at evaluating MAGO plasma conditions suitable for subsequent implosions. Our computations, which predict a 150- to 300-eV plasma, are in excellent agreement with experimental observations. Although the neutron-producing component of the plasma is not the primary interest from a MAGO / MTF perspective, the October experiment produced 1 x 10^{13} fusion reactions—a Los Alamos nonfission-driven record.

Pegasus Liner Gap Experiment

J. L. Stokes [(505) 667-4900], D. Platts (P-22), D. S. Sorenson, N. S. P. King (P-23), H. Oona (DX-15), W. Anderson (MST-7), P. Adams, J. Guzik (X-2), Pegasus Operation, Recording, and Analysis Team

The first shot in the liner gap experimental series was fired on August 12, 1994. This shot was the first classified weapons physics experiment done at the Pegasus Facility. The liner driver developed for the liner-ejecta experiments was used to drive a shock into a new target designed by members of X-2. The target construction was successfully done by an MST-7 team with novel materials. The objectives of the shot involved the performance of the target as a function of time. A laser backlighter and imaging system was developed to image the shock front as it propagated through the target. One image of the propagating shock was taken with a high-resolution camera system. Baseline data of the material motion was obtained with triple-axis radiography. A team from the Atomic Weapons Establishment, United Kingdom, provided imaging, Faraday rotation, and B-dot diagnostic support. The second shot in this series was fired on September 1, 1994. We successfully obtained good data on all experiments. Time-dependent laser backlit images, recorded both electronically and on film, gave the shock front as a function of time as it passed through the target. Triple-axis radiographic images were obtained. High-resolution optical images viewed the target radially at two different times.

Automobile Wheel Sensor CRADA

L. R. Veeser [(505) 667-7741], P. J. Rodriguez, P. Forman (P-22)

We are continuing to make progress in understanding our fiber-optic wheel-speed sensor. It consists of a thin bismuth-iron-garnet crystal on the end of a fiber near a rotating disk containing 50 magnetic pole pairs. The disk will be attached to the automobile wheel bearing and will rotate with it. Light from a diode laser or a light-emitting diode enters the crystal from the fiber and is reflected from the back of the crystal back into the fiber. Ordinarily the crystal diffracts some of the light out of the beam, but when a magnet pole in the rotating disk comes near the crystal, the diffraction is reduced and the reflected beam increases. Alternatively, if all the diffracted and undiffracted light is collected, then a polarizer in front of the crystal will cause the signal to decrease in the presence of the magnetic field; the polarization direction in the crystal is rotated because of the Faraday effect. As the wheel rotates and the magnets pass the crystal, the signal modulates. The frequency of the signal modulation determines the wheel speed for the speedometer, antilock-braking, and electronic-traction-control systems. Manufactures expect to change from electrical to optical communication on their cars within a few years; in that case, optical wheel-speed sensing will be very useful. Our research is presently looking into the behavior of the magnetic domains and at better ways of coupling in the laser light so that it is spread over many domains. With better understanding, we expect to be able to use the sensor also as a magnetic-field diagnostic for pulsed-power applications.

Russian Collaborations: X-ray Production Experiment

L. R. Veeser [(505) 667-7741], J. S. Shlachter, P. J. Rodriguez, B. G. Anderson (P-22), Collaborators from X Division, DX Division, and the Nuclear Weapons Program Office

As part of our efforts to study the production of multi-megajoule x-ray pulses from current-driven implosions of plasmas from materials such as thin metal cylinders (liners), we carried out a joint experiment designed and fielded at Arzamas-16 in Russia. The current in this experiment was produced by a disk-explosive magnetic generator, which economically and compactly converts chemical energy into an electrical pulse through magnetic flux compression. Instead of being produced directly from the implosion of a thin liner, the plasma was formed when a slowly moving heavy metal liner broke loose from one of its end electrodes, interrupting the 50-MA-current flow into the liner. The arc that formed at the electrode created a plasma that imploded onto a diagnostic package at the center of the cylinder. (In this first experiment, we elected to place the diagnostics where they would interrupt the implosion before it reached the center where it could generate x-rays.) We characterized the implosion with inductive, optical, and microwave sensors. Early data analysis indicates that although the plasma density and velocity were high enough to produce a good x-ray source, the symmetry was not. The arc apparently formed prematurely and asymmetrically. Now we are studying whether there is an adequate fix, such as a better liner-clamping system, which would warrant further experiments.

Shock Wave Studies

L. R. Veeser [(505) 667-7741], D. A. Clark, R. D. Fulton, D. M. Oro, P. J. Rodriquez, B. L. Wright (P-22), N. S. P. King (P-23), R. R. Bartsch (P-24), Collaborators from EG&G Energy Measurements, Inc.

We are developing diagnostic tools to study the uniformity of a high-pressure shock wave and the material emitted or spalled as it unloads from a metal into a vacuum or a gas. At a pressure of 300 kbar, for example, the temperature of the shocked surface is only a few hundred degrees above room temperature; therefore, there is almost no visible light available for diagnostics. Most of the radiation is in the infrared. We have purchased a Russian infrared framing camera that can photograph a shocked surface on a microsecond time scale. Initial work indicates that the camera works as advertised, about ten times more sensitive (and therefore ten times faster) than any infrared camera we had ever seen before. We have begun to build an infrared temperature diagnostic that consists of mercury-cadmium-tellurium crystals to detect the intensity of the infrared radiation for temperature measurements. We have purchased a picosecond-pulse, titanium-sapphire laser and a state-of-the-art streak camera to measure the amount of scattering from the cloud of material emitted after the shock breaks through the surface. This system, which will work much like lidar, will allow us to determine the location of the scattering particle density based on the arrival time of the signal at the streak camera.

P-23: Neutron Science and Technology

Fermilab Experiment E772: Study of the Nuclear Antiquark Sea via $p + A \rightarrow \mu^+\mu^- X$

D. M. Alde [(505) 667-9428] (P-23), J. G. Boissevain, T. A. Carey, G. T. Garvey, J. S. Kapustinsky, M. J. Leitch, P. L. McGaughey, J. M. Moss, W. E. Sondheim, J.-C. Peng (P-25), Collaborators from Abilene Christian University, the University of Chicago, Fermi National Accelerator Laboratory, the University of Illinois at Chicago, Lawrence Berkeley Laboratory, the Institute of Physics at Taiwan, Northern Illinois University, and the University of South Carolina

In Fermilab E772, a fixed-target experiment, data were collected from June 1987 through February 1988. The experiment far exceeded its original objectives. It was the first high-statistics study of the *A*-dependence of the Drell-Yan process. Data on $p + A \rightarrow \mu^+\mu^- X$ were measured using four heavy targets (carbon, calcium, iron, and tungsten) and a cryogenic ^{2}H target. The reported yields per nucleon, $R = Y_A/Y^2{}_H$, are accurate to better than 2% systematic error. The experiment produced the first measurement of the *A*-dependence of the Ψ' resonance. It also produced the first significant measurement of the *A*-dependence of the Y family of resonances. During 1994, the group analyzed data collected during the physics run and published several papers.

P-23 Piranha Van

K. R. Alrick [(505) 667-2904] (P-23)

P-23 has the ability to record transient and imaging data at remote locations using a mobile recording facility known as the “Piranha Van.” The Piranha Van is actually a 26-ft delivery van that has been modified by EG&G Energy Measurements, Inc., to house a state-of-the-art digital recording system. The system consists of four equipment racks along with a wide range of transient recorders and other components that can be controlled and read by a 486 PC through an IEEE488 bus. Current software supports Lecroy TR8818A transient digitizers, Teltronix RTD720 transient waveform digitizers, and Tektronix SCD5000 transient event digitizers. The facility is cooled by two roof-mounted recreational-vehicle air-conditioning units and can be powered at remote locations by a companion 20-kW diesel generator. Having been designed for use on movie sets, the generator is both quiet and efficient. During the last year, the Piranha Van has been used to record data from experiments at the Trident laser facility and from experiments at several high-explosive test sites.

Ultracold Neutron Research

T. J. Bowles [(505) 667-3937], S. J. Seestrom, G. Greene (P-23)

Ultracold neutrons (UCNs) are neutrons whose wavelengths are sufficiently long (typically greater than 500 Å) that they can undergo total internal reflection at all angles from the surfaces of a variety of materials. UCNs can therefore possibly be totally confined within a bottle for periods in excess of 100 s, making a compact source of stored neutrons for use in measurements of fundamental physics. There is a wide variety of other fundamental physics measurements that can benefit greatly from a UCN source, including measurements of the electric dipole moment of the neutron, the neutron lifetime, and measurements of other angular correlations in neutron beta decay. There is also interest in using UCNs to study gravity, other properties of the neutron (*e.g.*, possibly electric charge), and other fundamental measurements. UCNs are also likely to be of interest in other areas of research, including materials science, as they are highly sensitive probes of surface properties of materials in contrast to thermal neutrons, which probe bulk properties. Because neutrons can differentiate between light elements (such as hydrogen) and heavy elements (such as iron) and because they are sensitive to the magnetic properties of the material, UCNs offer a unique new tool to study materials. One can take advantage of the pulsed nature of the (Manuel Lujan) Los Alamos Neutron Scattering Center (LANSCE) source to produce and store UCNs at the available peak intensities, which are comparable with, or can exceed that of, a reactor. A UCN Facility, which will use Flight Path 11 at LANSCE, is now under construction. A guide tube, together with the required shielding, will be used to transport cold neutrons out to the UCN converter. A 6-cm x 6-cm crystal moving at a velocity that is one-half of the incident neutron velocity will be installed on the end of a rotor, which rotates in synchronism with the beam pulse rate (20 Hz). The crystal moves away from the incoming neutron pulse and Bragg scatters and Doppler shifts the neutrons down into the UCN regime. UCNs produced at the rotor would pass through a shutter (which allows the puff of UCNs into a guide tube to the experiments in synchronism with the beam pulses and is closed between beam pulses to prevent UCN losses). The UCN guide will end in a neutron bottle with a volume of up to 100 l. We anticipate UCN densities of 10 to 20 UCNs/cm^3 compared with the best in the world at the Institut Laue Langevin (Grenoble, France) reactor of 87 UCNs/cm^3. An upgrade for a new coupled liquid-hydrogen target planned for FY97 at LANSCE would increase the density to 30 to 70 UCNs/cm^3. We plan to first carry out measurements of angular correlations in neutron beta decay at the UCN source now under construction at LANSCE. These measurements will allow us to determine the weak-interaction axial-vector coupling constant, which is a fundamental constant of nature, and will provide sensitivity to the possible existence of right-handed currents, a topic currently of great interest in the field. The development of cryogenic moderators (such as frozen deuterium) offer prospects of an increase of a factor of 100 in UCN densities over rotor sources. Such a source would be of particular interest at a Long Pulse Spallation Source (LPSS). The Laboratory has listed a UCN source at an LPSS as its highest priority for a new facility in nuclear physics. We expect to complete a pre-engineering design study by the end of FY96; this study would determine the feasibility of using such a moderator at an LPSS.

Radiography with High-Energy Neutrons

A. Gavron [(505) 667-5475], A. Bridge, W. P. Abfalterer, S. J. Seestrom, J. L. Ullmann, N. S. P. King, G. L. Morgan (P-23), C. L. Morris, M. M. Murray, D. M. Lee, J. D. Zumbro (P-25), Collaborators from Lawrence Livermore National Laboratory

At the Weapons Neutron Research (WNR) Facility, we are evaluating the use of high-energy (up to 600-MeV) neutron beams for imaging light materials embedded in thick, heavy materials. X-rays, widely used for radiography, have a very poor contrast for low-Z materials, compared with high-Z materials. Neutrons are scattered and thus removed from a beam more readily by low-Z elements as compared with x-rays, thus providing a better contrast for light materials. Although slow neutron radiography has been used for many years as a nondestructive testing technique, the use of higher-energy neutrons is a novel concept. A 2.54-cm-thick sample of ^{6}LiD was placed between two 5-cm-thick samples of uranium metal as a test of the thickness of heavy metal through which clear images of light material can be obtained. Holes of various sizes were drilled in the ^{6}LiD sample, some completely through the thickness of the sample and some halfway through. Clear images of all the holes were obtained by irradiating the sample with a flux of neutrons in the 40- to 400-MeV energy range. We feel that the capability of the neutron radiographic technique has been demonstrated and that it has potential important applications in nuclear-weapons stockpile surveillance.

MILAGRO

T. J. Haines [(505) 667-3638], C. G. Sinnis (P-23), C. M. Hoffman (DDP/P-23), D. Schmidt (P-21), G. E. Hogan, V. D. Sandberg (P-25), G. Gisler (NIS-2), Collaborators from the University of Maryland, the University of California at Irvine, the University of California at Santa Cruz, the University of California at Riverside, the University of California at Santa Barbara, George Mason University, and New York University

In the decades-old study of cosmic radiation, the source(s) of energetic rays above about 1 GeV has not been identified. Because charged particles are deflected in the galactic magnetic field, gamma rays are potential indicators of localized cosmic-ray sources. Charged particles and gamma rays interact in Earth's atmosphere and dissipate their energy by creating a cascade, or air shower, of secondary particles. As the air shower progresses through the atmosphere, the number of charged particles and gamma-rays increases, and the energy per particle decreases. In collaboration with colleagues from a number of universities, P-23 operates an air-shower detector called CYGNUS, which measures charged cosmic rays and gamma rays in the energy range around 10^{14} eV. CYGNUS is an array of 200 scintillation counters, each with about a 1-m^2 area and separated by about 15 m. CYGNUS has been recording data continuously since early 1986. Except for an apparent burst from the x-ray-binary Hercules X-1, which occurred in 1986, no evidence for an astrophysical source of gamma rays has been found. The CYGNUS observations place stringent constraints on models of cosmic-ray production. Over the past several years, P-23 has led the development of a new-generation air-shower detector called MILAGRO, a 5,000-m^2-area, 8-m-deep tank that will be instrumented with 800 phototubes. The MILAGRO tank is an existing pond located at the Fenton Hill Geothermal Project (TA-57) 35 miles west of Los Alamos. The phototubes will detect Cerenkov radiation (light) produced by incident air-shower particles as they pass through the tank and interact with the water. Because MILAGRO will detect nearly all particles present in an air shower, including gamma rays that substantially out number charged particles, the detection threshold will be around 500 GeV, which is about 100 times lower than that of CYGNUS. The lower threshold and excellent angular resolution of MILAGRO will make the first search of the sky for astrophysical gamma-ray sources in the TeV (10^{12} eV) energy range possible. MILAGRO will be especially suited for study of episodic or transient gamma-ray sources (*i.e.*, for recording gamma-ray bursts). MILAGRO is currently under construction; completion is planned for 1998.

Comprehensive Nuclear Test Ban Monitoring

R. E. Hill [(505) 667-8754] (P-23)

One critical consideration for U.S. entry into a Comprehensive (Nuclear Weapon) Test Ban Treaty (CTBT) is monitoring, *i.e.*, detecting, locating, and identifying clandestine nuclear explosions. One technique under consideration is detecting and recording acoustic waves generated in the atmosphere. At distances up to 2,000 km, explosion-generated waves have a frequency content in the band 0.1 to 10 Hz; at greater distances, the band of interest is 0 to 0.1 Hz. Because the frequency bands are below the audible range, the waves are referred to as “infrasound.” Two classes of infrasound detectors are under consideration: (1) a type of microphone for the first band and (2) microbarographs for the second. The Air Force Technical Applications Center (AFTAC) operates a U.S. monitoring system that includes a facility known as the National Data Center (NDC). The NDC receives and evaluates all information from ground-based and satellite stations that comprise what is known as the National Technical Means (NTM) for treaty monitoring. Infrasound is presently under consideration for inclusion as part of the NTM system. As part of an experimental program to monitor underground nuclear explosions, Los Alamos has installed three microphone stations in Los Alamos, the NTS, and southern Utah. During 1994, P-23 implemented a high-speed data link between Los Alamos and the AFTAC and provided hardware and software so that data recorded by the microphones from the three stations could be transmitted continuously to the NDC over dedicated telephone lines. If the NTM system is expanded to include infrasound-recording stations, P-23 will have a significant role in the design and demonstration of the data-acquisition and -analysis subsystems.

Quantum Cryptography

R. J. Hughes [(505) 667-3876], G. L. Morgan, P. Dyer, D. M. Alde (P-23), D. Tupa (P-25), G. G. Luther (P-22), M. M. Schauer (P-24)

The two main goals of cryptography (the science of secret communications) are (1) the encryption of a message to render it unintelligible to a third party and (2) authentication of a message to certify to the legitimate recipient that it has not been altered in transit. Both of these objectives can be accomplished, with provable security, if the sender and recipient possess a secret random bit sequence (key material). Clearly, the distribution of key material between the two parties must be accomplished without revealing the material to third parties. If the two parties communicate solely through classical messages, it is impossible for them to generate a certifiably secret key. However, secure key distribution becomes possible if the two parties communicate with single-photon transmissions using the emerging technology of quantum cryptography: Heisenberg’s uncertainty principle ensures that an eavesdropper’s measurements can yield only incomplete information about the quantum states used for key generation and will irreversibly alter these states in a way detectable by the sender and intended recipient. We have developed an optical fiber implementation of quantum cryptography that uses single-photon interference at a 1.3-μm wavelength to compare and distill a shared, secret subset of bits (the key material) from initial, independent random number sets generated by sender and recipient. A photon is sent to the recipient for each bit in the sender’s initial random number set. The sender uses his/her random bit value to set the phase of one of two interfering quantum-mechanical probability amplitudes for photon propagation to the recipient, who sets the phase of the other amplitude according to his/her bit value. The two possible phase settings for each amplitude produce destructive single-photon interference when the sender and recipient have different bit values (*i.e.*, the photon does not arrive at the detector) but conversely constructive interference when the bits are the same. Thus, the detected photons indicate which bits the sender and recipient have in common, and these are retained forming the shared, secret cryptographic key. We have demonstrated key distribution in a laboratory environment, and in FY95 we expect to establish a demonstration quantum cryptographic link over installed optical fibers between two Los Alamos technical areas separated by a distance of 7.5 km.

Biomedical Application of Fast Imaging Cameras

N. S. P. King [(505) 667-4415], G. J. Yates, K. R. Alrick, S. A. Jaramillo (P-23), Collaborators from Henry Ford Hospital

With the staff of the Bone and Joint Center, Henry Ford Hospital, Detroit, Michigan, P-23 demonstrated a proof-of-principle instrumentation system for high-speed recording of x-ray images. In the context of medical diagnosis, “high speed” is a frame rate of 1,000 Hz and shutter interval of 100 µs with acceptable image quality. The ultimate objective of the project is to provide a prototype system for high-speed recording of x-ray images of animal or human body parts in motion (*e.g.*, the details of motion of the structure of a human knee when stressed in running or walking). The proof-of-principle system, which was demonstrated at the hospital in 1994, included a standard x-ray machine as the x-ray source and test objects consisting of metallic spheres embedded in a rotating plastic disk. Acceptable images of the spheres moving at 20 m/s were recorded from a P-23-developed camera with a Vidicon image tube that operates at a rate of 1,000 frames per second. A second P-23-developed charge-coupled-device (CCD) camera with comparable but somewhat lower frame rates was also operated at the hospital. The CCD camera has an advantage over the Vidicon image tube in that it produces higher fidelity images. The demonstration was considered highly successful in showing the feasibility of the cameras for use in biomedical research and diagnostics. Further work on a prototype is anticipated.

Accelerator Production of Tritium

G. L. Morgan [(505) 667-1137], J. L. Ullmann, P. A. Staples, N. S. P. King (P-23), A. Bridge (P-23), G. W. Butler (CST-11), P. W. Lisowski, M. Cappiello (LER/APT), Collaborators from EG&G Energy Measurements, Inc., and Lawrence Livermore National Laboratory

In support of the APT Program, P-23 is participating in a number of investigations related to the physics of the target/blanket system. These investigations include experiments at WNR to measure the total neutron production and tritium production by 800-MeV protons in a benchmark target assembly. Diagnostic instrumentation is being developed to monitor neutron and tritium production in a full-scale target assembly to be tested in 1998. Supplementary experiments to measure total neutron production as a function of proton energy on lead and tungsten targets are being initiated at the Saturne accelerator in Saclay, France. In addition, work is in progress on the production of radionuclides by high-energy protons in targets of lead, tungsten, iron, and aluminum. These data are important to benchmark the computer code system (LAHET/MCNP), which is used to predict inventories of radionuclides in the target and coolant systems. WNR will also be used to develop imaging systems capable of diagnosing the performance of the APT beam-expander system. This system will be used in 1997 to characterize a prototypic beam expander capable of expanding the Los Alamos Meson Physics Facility (LAMPF) beam to an area of about 5,000 cm^2.

Gamma-Ray Production Measurements

R. O. Nelson [(505) 667-7107], S. A. Wender, D. R. Mayo (P-23)

High-energy gamma-ray production from fast-neutron-induced reactions on actinide samples is of interest for programmatic reasons and for basic nuclear physics. The high-energy gamma-ray measurements at the WNR white neutron source at LAMPF cover a gamma-ray energy range from a few MeV to 30 MeV and a neutron energy range that extends from a few MeV to well over 25 MeV. The dominant contribution to the gamma-ray spectrum in the 10- to 30-MeV energy region is expected to come from neutron-capture reactions. Such measurements are very difficult because of the small capture cross section and because of the large neutron and gamma-ray backgrounds typically encountered. BGO (bismuth germinate) detectors measure the gamma-ray signals from neutron interactions with the actinide samples with good efficiency but with relatively poor gamma-ray energy resolution. In the past year, substantial improvements have been made in the background subtraction and in the deconvolution procedures needed to reduce the data taken with the BGO detectors. Germanium detectors lack the good efficiency of BGO but have very high gamma-ray energy resolution. High-resolution germanium detectors are used at the WNR to measure individual transitions in reaction product nuclei. This information enables us to observe individual reaction channels as a function of incident neutron energy. Measuring individual reaction channels allows us to obtain detailed excitation function data with the white neutron source for reactions such as (n,xn) [x=2,3,...], which are accessible by the higher-energy neutrons at WNR; these particular reactions are difficult to measure by other means. Such data are useful for testing the validity of model calculations in the largely unexplored incident-neutron energy region above 20 MeV and have numerous applications in science and technology. The efficiency of our germanium detectors limits measurements of gamma rays to energies below 8 MeV. In 1994, the experimental setup was extended to allow measurements of gamma-ray angular distributions. Data acquired on C, ^{14}N, and ^{15}N complement earlier data acquired with the BGO detectors.

AGEX II

D. S. Sorenson [(505) 665-2860] (P-23)

P-23 provided instrumentation and recorded and analyzed data as part of a number of aboveground experiments (AGEX II) at the Los Alamos Pegasus II and Procyon facilities. The experiments consist of recording the motion of assemblies imploded by magnetic forces. An imploding pressure is generated by passing the current from a capacitor bank through an annular conductor within which a test object is placed. Currents of sufficient magnitude are available to reach pressures that cause implosion of test objects representing nuclear systems. Records of implosions include optical images of the external structures and x-ray images of internal test objects. P-23 provided cameras and timing circuitry that were needed to achieve a number of images for each experiment and had sufficient spatial and temporal resolution to record the dynamics of the implosions. Adopting instrumentation developed by P-23 for diagnostic measurements of underground nuclear explosions to AGEX II requirements allowed the experimental program to proceed with little delay. During FY94, P-23 participated in fourteen experiments at the Pegasus II Facility and two experiments at the Procyon Facility. The phenomena observed by P-23 included radiation flow, liner ejecta, and liner gap. Diagnostic instrumentation provided by P-23 included visible-image, holographic-image, and x-ray-image recorders.

Archival of Prompt Diagnostic Data from Tests of Nuclear Devices
M. L. Stelts [(505) 667-1507], D. S. King, M. S. Moore, A. McGuire, P.-J. Liu, T. O. McKown, R. Walton, R. Wakefield, F. H. Cverna, S. M. Sterbenz, R. C. Haight, A. W. Obst (P-23)

Los Alamos has acquired much data on the performance of nuclear devices over the years. With the cessation of nuclear testing and with the charge of the Scientific-Based Stockpile Stewardship to certify the performance of weapons in the stockpile, these data are crucial to the improvement of the physical models and to the certification of new computer codes describing the performance of nuclear devices. The information that we are responsible for concentrates on precision measurements of neutron leakage and on imaging sources of radiation produced by nuclear devices. We are engaged in collecting the data and other pertinent parameters and in storing them in a logical structure in a computer archive. This work often involves the reanalysis of experiments. We include files describing the experiments in detail with all information to compare calculations of device output with the experiments. Procedure files are written to guide the user of the data through the necessary steps to perform the calculations. We are also writing handbooks about the experiments: history, design, analysis, and interpretation. In this way, we hope to preserve our corporate knowledge for the future.

n-p Bremsstrahlung at the Weapons Neutron Research Facility
T. N. Taddeucci [(505) 665-3114], D. R. Mayo, S. A. Wender, R. O. Nelson (P-23)

Neutron-proton (n-p) bremsstrahlung is a fundamental two-nucleon process that is sensitive to meson-exchange currents and the off-shell character of the nucleon-nucleon interaction. Substantial progress has been made toward performing successful differential measurements of the n-p bremsstrahlung process by measuring neutrons and protons in coincidence from neutron interactions in a liquid hydrogen (LH_2) target. A refurbished LH_2 target, better beam collimation, and reconfigured detectors and electronics were the key features of the experimental setup for measurements made in 1994. Three conjugate-angle detector pairs were used for initial measurements of elastic n-p scattering. The goal of these measurements was to use the well-understood elastic-scattering reaction to demonstrate that n-p coincidences could be cleanly observed; the reaction was then used to characterize background and to develop analysis techniques for extracting n-p bremsstrahlung coincidence events. Proton detectors were positioned to the right of the beam at angles of 20°, 28°, and 36° at a distance of 60 cm from the center of the LH_2 target. Neutron detectors were stationed to the left of the beam at conjugate angles of 51.2°, 59.5°, and 68° at a distance of 220 cm. Measurements made with this geometry demonstrated that elastic n-p coincidence events could be very cleanly separated from background. Data were also obtained with the neutron detectors moved into a symmetric geometry that matched the scattering angles of the proton detectors. This geometry is necessary to observe inelastic processes. These data should contain a good sample of n-p bremsstrahlung events. Replay and analysis of the data from the 1994 running are still in progress.

n-p Scattering from 50 to 250 MeV
J. L. Ullmann [(505) 667-2517], W. Abfalterer (P-23), B. K. Park (P-25), Collaborators from Ohio University and Ohio State University

The elementary n-p reaction plays a fundamental role in nuclear physics because it forms the basis for all neutron-nucleus interactions, as well as being of fundamental interest itself. This reaction also is a commonly used calibration standard for neutron-induced reactions. Recently, it has attracted much theoretical attention as a means of inferring the πNN strong-interaction coupling constant, recent values of which differ by 5 standard deviations from previous work. Although this fundamental cross section should be well known, recent measurements of the cross section near 0° have differed substantially from earlier measurements at 95 and 162 MeV. The WNR white neutron source provides a unique capability to measure the cross section continuously as a function of energy. During the 1994 beam cycle, we attempted to measure this cross section from 50 to 250 MeV. We took data over three angle ranges up to a 50° proton angle in the laboratory (approximately 80° in the center of mass). A clearing magnet was used to measure protons scattered near the crucial 0° angle. The data are currently being analyzed.

Image Intensifier Development
G. J. Yates [(505) 667-7529], N. S. P. King (P-23)

This work represents a refinement of our earlier efforts to develop transmission-line gating techniques for modified proximity-focused microchannel-plate image intensifiers (MCPIIs), which incorporate stripline geometry designed by P-23 and fabricated by RTC Philips, Inc. The focus was on developing improved impedance transforms and coupling between 50-Ω gate pulse generators and 5-Ω MCPII gate interface so that pulse reflections and dispersions (which cause temporal broadening of the electrical pulse with consequential increases in shutter time or optical gate) are minimized. Modeling of the MCPII gate interface (the PC/MCP junction) gave ≈ 5-Ω impedance at GHz frequencies. We designed a microstrip with approximately a one-quarter wavelength linear taper and ≈ 4.5-cm-long 5-Ω sections to give constant impedance at the gate interface for a 100- to 200-ps gate pulse. The 18-mm MCPII had an S-20 photocathode (PC) with 50% optical transmissive Ni undercoating (giving composite sheet resistance of ≈ 50 Ω/square), an MCP with gold flashing on its input surface (which gives sheet resistance of ≈ 20 Ω/square), a P-20 phosphor screen, and planar PC and MCP electrode leads. The MCPII was attached to the microstrip transmission line and gated with ≈ 290-ps FWHM (full-width at half-maximum), -500-V pulse from a 50-Ω source impedance generator. The microstrip transforms the 50-Ω impedance to 5 Ω as required, but the pulse amplitude undergoes attenuation by about 3.2, proportional to the square root of the ratio of the two impedances. The technique was successfully used to optically gate the MCPII in ≈ 200 ps by driving with ≈ 290-ps FWHM pulse capacitively coupled to the microstrip transformer, which was reverse biased to ≈ 90 V. The limiting resolution at the center of the optical gate was ≈ 8 line pairs per millimeter. These results are compared with our earlier tests using straight-taper designs, which gave minimum optical gates in the 500- to 700-ps range.

Mine Detection Project

G. J. Yates [(505) 667-7529], S. A. Jaramillo, K. R. Albright (P-23)

The mine-detection project involves the development of a range-gated video system for the Marine Corps for detecting mines in shallow sea waters on prospective assault beach fronts. This on-going project is in its fourth year. Progress this year included design of circuitry to control, measure, and encode image intensifier gain and shutter gate width to l0-bits dynamic range with l-bit resolution. The circuitry provided “real-time” control, which was updated with every TV frame, annotated with the video waveform, and stored in a central processing unit as binary files. Gate resolution was 1 ns with a range of 1.24 µs. Gain resolution was 1 V in the 1,024-V range. The system was successfully deployed by a Los Alamos and a U.S. Navy Coastal System Station (CSS) team in the field at the CSS in Panama City, Florida. Test plans, which called for a fall 1994 deployment of the PIER TEST phase of the video system in the Bahama Islands, have been rescheduled for fall or winter 1995. The work was carried out for the Marine Corps under the new program name “Magic Lantern Adaptation,” which is a component of a larger, but similar, U.S. Navy program.

Radiation Testing of Solid State Imagers

G. J. Yates [(505) 667-7529] (P-23)

Tests were conducted on several CCDs and charge-injection devices (CIDs) to study permanent damage thresholds from accumulated doses of ionizing radiation. This project was funded by the Laboratory’s Industrial Partnership Office (IPO) under their Small Business Initiative Program—a cooperative agreement with industry to use Laboratory capabilities to solve industrial problems. Experiments were conducted with the EG&G Energy Measurements, Inc., DOE electron linear accelerator (and bremsstrahlung target) to measure variable width pulses of high-energy (*i.e.*, up to 12-MeV end-point energy) x-rays and their ^{60}Co source range for gamma irradiation. The sensors were exposed to different flux levels to produce a total given dose at different rates to study optical sensitivity as functions of both absorbed dose, as well as dose rate involved in the exposures. The imagers evaluated included Fairchild CCD-222; English Electric Valve, Inc., CCD 07-06; CID Technologies, Inc., CID20-21; and CID 35HSA. The CID 35HSA showed some loss in optical sensitivity at 20 to 30 krad. The CCD-222 and CID20-21 sustained permanent damage at 10 to 100 krad, but the CCD 07-06 showed no permanent damage although its gamma sensitivity exceeded the other two. The permanent damage is seen as increased dark current at the exposed location. The increased dark current was evident immediately following exposure for the CID, but the CCD damage was not observed until several days later when the device was re-activated. This work involves on-going research as new radiation-hardened devices, which can withstand Mrad doses, are developed.

Solid-State Test Station

G. J. Yates [(505) 667-7529] (P-23)

P-23's high-speed solid-state test station (HSTS) was used to evaluate three newly developed scientific-type multiport CCD imagers. All three imagers were federally funded as research for DOE and DoD military applications. The CCDs are English Electric Valve, Inc., Model CCD-13; EG&G Reticon Model HS0512J; and David Sarnoff Laboratory Model HOL5121F002. All are 512 x 512 pixel arrays, and all are Frame Transfer CCDs. The CCD-13 is an 8-port device with no on-chip storage, whereas the other two CCDs are 16-port devices with split upper and lower on-chip storage areas. The HSTS was used to test key responses, including charge transfer efficiency, resolution, dynamic range, crosstalk, and sensitivity at variable pixel data rates from 10 to 50 MHz. The salient test results were presented at SPIE's International Symposium on Optics, Imaging, and Instrumentation (San Diego, California, July 24-29, 1994) and at the IEEE Nuclear Science Symposium and Medical Imaging Conference (Norfolk, Virginia, October 30–November 5, 1995). The work was performed for the British Atomic Weapons Establishment, the U.S. Air Force's Wright Laboratory Armament Directorate, and the Army Research Laboratory under an informal agreement to use Los Alamos' unique test capabilities in exchange for samples of the three CCDs. The HSTS, which has a patent pending, has been advertised via Internet for commercial use by the IPO as "Facility for Detailed Characterization of Cameras Having up to 10^4 Pixels per Second."

P-24: Plasma Physics

Neutron Measurements on MAGO I

R. E. Chrien [(505) 667-1674] (P-24), P. Rodriguez (P-22)

Time-resolved and time-integrated neutron measurements were obtained on the MAGO I experiment at the Arzamas-16 Laboratory in Russia. These measurements were fielded to check the Russian results indicating 1 x 10^{13} D-T neutron yield in a 1-µs pulse duration. Scintillator-photodiode and -photomultiplier detectors were located at 2 m and 66 m from the MAGO chamber. Activation samples were located on the chamber wall and at 3.9 m from the chamber. The copper sample, which indicated a yield of 0.67 x 10^{13}, is in agreement with the Russian samples. The calibrated, time-resolved detectors gave similar yield estimates and also indicated the presence of a component of 15-MeV neutrons during the initial part of the MAGO neutron pulse. This component of the fusion reactions indicates the presence of some directed ions with 100- to 150-keV energy, and it is interpreted by the Russians to be associated with the nozzle region of the MAGO chamber.

Tion Diagnostic on Nova

R. E. Chrien [(505) 667-1674], K. A. Klare (P-24)

A high-sensitivity, high-resolution, neutron time-of-flight spectrometer is operating on the Nova laser facility at Lawrence Livermore National Laboratory. This spectrometer consists of 1,020 scintillator-photomultiplier channels located 27 m from a Nova target. The diagnostic was designed to determine the fusion-weighted ion temperature in Nova implosions from the thermal-induced broadening of 2.45-MeV DD fusion neutrons. Three interchangeable sizes of scintillators allow the diagnostic to cover the full range of indirect-drive neutron yields on Nova from 2 x 10^7 to 5 x 10^9. The energy resolution measured on direct-drive targets containing 1% tritium and 99% deuterium fuel is 22 keV. The fractional uncertainty of the ion-temperature measurement is typically 10% for 200 detected neutrons. Measured ion temperatures have varied from 1 to 4 keV in different Nova targets. Neutron energy spectra caused by nonthermal ions have also been detected from gas-filled hohlraums containing deuterated neopentane and from surface-blow-off phenomena in special targets.

Intense Ion Beam for Materials Processing

J. C. Olson [(505) 665-3193], H. A. Davis, W. J. Waganaar (P-24)

We are working with major U.S. companies, other national laboratories, and universities to apply the intense ion-beam technology developed for the ICF program to the production of advanced and novel materials. We have developed the capability to generate beams with a wide range of ion energies (100 to 500 keV), a wide range of currents (10 to 40 kA), and a wide range of pulse durations (0.4 to 2 µs). Total beam energies of up to 3 kJ are available for direct treatment of materials and for film growth by ablative deposition. Films are grown by condensing target material, which has been vaporized by the ion beam, onto a substrate. Extremely high rates of deposition are obtained, and the stoichiometry of the target material is preserved. Diamond-like carbon and $YBa_2Cu_3O_{7-x}$ are just two of the films that have been produced by this method. Materials have also been treated by direct exposure to the ion beam. This process results in a rapid melt / recrystallization of the target material and has been demonstrated to increase hardness, wear resistance, and corrosion resistance and to decrease grain size, surface roughness, and friction. Future plans for this project include continued process development for both film-growth and direct-treatment applications; fielding of an improved ion source to reduce debris and to improve energy coupling to the ion beam; and the development of the capability to produce uniform, reproducible ion beams at pulse rates of up to 1 Hz.

Plasma Source Ion Implantation

C. Munson [(505) 667-7509], I. Henins, W. A. Reass, J. T. Scheuer, B. P. Wood (P-24), M. A. Nastasi, K. C. Walter (MST-4), R. J. Faehl (X-5)

Plasma source ion implantation (PSII) is rapidly being recognized as a cost-effective alternative to the more conventional ion-beam implantation for the surface modification of materials. In the PSII process, the object to be implanted is immersed in a plasma containing the desired implantation species (nitrogen, carbon, boron, or metallic ions), and the ions are drawn into the surface by the application of short (~20 µs), high-voltage (*i.e.*, of the order of -100 kV) pulses. PSII has been shown to produce dramatic increases in material surface hardness and resistance to corrosion, and the fundamental process has been well characterized by conventional ion-beam implantation. Like ion-beam implantation, PSII is an environmentally friendly technology, requiring no hazardous chemical baths for processing and producing essentially no waste stream. Unlike ion-beam implantation, which is inherently a line-of-sight process, PSII can treat essentially the entire surface of an object simultaneously and requires no in-vacuum manipulation of the treated object. Elimination of the need to manipulate the target in vacuum and the ability to implant large surface areas or multiple components simultaneously are the bases for the predicted cost reductions in PSII as compared with conventional ion implantation. As part of a three year CRADA involving Los Alamos, General Motors, and the University of Wisconsin, we have assembled the world’s largest PSII Facility. The facility is a 1.5-m-diam by 4.6-m-long vacuum chamber with a high-voltage switching system capable of 60-A, -120-kV pulses with an average current of 2.4 A. It is being used to develop and verify PSII-based processes for use in extending the life of automotive components, industrial tools, and dies and to scale these processes for use on large-surface-area components and multiple smaller components. Nitrogen implantation has been performed on objects with surface areas as large as 4.6 m^2, and as many as 80 nonferrous power train components (NFPTCs) have been processed simultaneously. The surface modifications produced in the NFPTCs through PSII-based processing have been increased by a factor of almost 20 in surface hardness and reduced by almost a factor of 2 in the coefficient of friction. These modifications have resulted in greatly enhanced component lifetimes in the bench-level tests completed to date. A full-scale test of NFPTCs processed at Los Alamos is currently under way. A proposal to continue the PSII research and development and to facilitate the transition of this technology to industry has been submitted to the National Institute of Standards and Technology Advanced Technology Program. The Advanced Technology Program proposal includes a broad based consortium of technology end users, component manufacturers, service providers, and Los Alamos National Laboratory.

Instabilities in Taylor-Sedov Blast Waves

G. T. Schappert [(505) 667-1294] (P-24), R. D. Fulton, D. M. Oró (P-22), Collaborator from University of Michigan

In a series of papers, Vishniac and Ryu [E. V. T. Vishniac and D. Ryu, *Astrophysical Journal* **337**, 917-926 (1989)] showed theoretically that under certain conditions the propagation of shock waves can be unstable even in a uniform gas. The criterion for instability was that the adiabatic index γ of the gas into which the wave propagates be below 1.2. A low γ can occur at certain densities and temperatures when excitation, ionization, and radiation processes increase the number of degrees of freedom. We have performed a series of experiments using the laser at our Trident Facility to investigate this instability. Preliminary results so far have shown that blast waves in xenon, nitrogen, and neon were unstable under a variety of experimental conditions, whereas blast waves in helium could be stable or unstable depending on how the blast was initiated. Further experimental work is needed to determine whether these observations confirm the criterion for instability.

Development of Magnetic Nozzles for Plasma-Flow Control

J. T. Scheuer [(505) 665-6525], K. F. Schoenberg, R. Hoyt, H. P. Wagner (P-24), Richard Gerwin (T-15), R. W. Moses, Jr. (NIS-1)

There are a variety of applications in industry, defense research, and space propulsion for directed-energetic plasma flows. For example, the use of accelerated plasmas for surface etching addresses a large and real environmental problem: the production of metal-contaminated ferric-chloride and heavy-metal-contaminated solvent wastes presently produced by wet-chemical etching. For these applications, magnetic nozzles provide an enabling capability to control the formation, acceleration, and focusing of plasmas. In FY94, we developed and tested a prototype magnetic nozzle for advanced, environmentally conscious manufacturing applications. This activity engaged fundamental physics of flowing magnetized plasmas in self-generated and applied magnetic fields. To aid in nozzle design, we initiated the development of a symbolic-algebra computational technique intermediate to simple point models (such as solving Bernoulli's equation for a single flow tube) and large two- or three-dimensional numerical magnetohydrodynamic (MHD) codes. This hybrid technique allowed us to include "nonideal" MHD effects (such as finite gyro radii) in modeling nozzle performance. Model results were compared with experimental results with excellent agreement. Under a CRADA with the 3M Corporation, supported by a DOE defense programs weapons support agreement, we demonstrated that magnetically nozzled plasma accelerators can achieve cost-effective industrial manufacturing requirements. 3M is presently commercializing the application of our magnetic nozzle system to the manufacture of a product line.

Contamination and Uniformity Control in Plasma-Processing Tools

G. S. Selwyn [(505) 665-7359], M. G. Tuszewski (P-24), M. Jones, D. Winske (X-1)

This project involves the design and evaluation of various ultraclean field-corrected electrodes, or wafer chucks, to improve process uniformity and particulate contamination in the plasma processing of semiconductor materials. The electrodes used by our partner, the original equipment manufacturer to the semiconductor industry, will be modified for field tunability, which is achieved by designing dielectric and/or metal tuning elements in the electrodes to compensate for electrode-induced plasma electrical aberrations. The resulting trap-free discharge greatly reduces particle contamination by canceling the net electrostatic confinement of particles in the discharge. The field-corrected electrode also improves process uniformity at the same time. Both factors dramatically improve manufacturing yield and reduce product cost. The proposed program involves three goals: (1) a passive (or fixed) field-tunable electrode for a high-density or conventional plasma tool, (2) an active (or externally controllable) field-tunable electrode for a high-density or conventional plasma tool, and (3) a code to help predict tunable-electrode design for future plasma tools. The success of this program will be measured by the improvement in particle contamination performance and edge uniformity over the base, unmodified tools. This program will provide a boost in the effort to link Laboratory talents and capabilities with the national needs of industry.

Detection of Ion Plasma Waves

R. G. Watt [(505) 665-2310], M. D. Wilke, G. Busch, S. E. Caldwell (P-24), Collaborators from Lawrence Livermore National Laboratory and EG&G Energy Measurements, Inc.

Los Alamos and Lawrence Livermore National Laboratory researchers collaborated on an experiment in which ion plasma waves were observed for the first time. Plasmas sustain a rich spectrum of wave motions. Until 1994, ion waves that were theoretically postulated to exist in plasmas had not been experimentally observed. An ion wave has a wavelength so short that the electrons cannot shield the electric field between clusters of positive ions. The electric field produced by the clusters causes the ion density to oscillate about a uniform electron background. Ion plasma waves are important in multiple-ionized plasmas, such as those in x-ray lasers, ICF, and some industrial-processing systems. The intense laser beams at the Los Alamos Trident Facility were used to generate a plasma with the properties required to sustain ion plasma waves. We characterized the plasma using x-ray diagnostics, interferometry, and optical scattering. Ion waves, evidenced by resonant scattering, were detected by probing the plasma with a less-intense laser beam. The existence of such waves was first postulated in 1929 and had escaped previous detection because in earlier attempts conducting electrodes placed in the plasma caused excessive damping. Los Alamos provided the Trident Facility, some of the plasma diagnostics, and recording capability and performed data reduction. Lawrence Livermore National Laboratory provided the spectrometer and the streak camera. Recording instrumentation was in part an adaptation of weapon-diagnostic techniques.

Suppression of Laser Nonuniformities in Inertial Confinement Fusion by the Use of Low-Density Foam

R. G. Watt [(505) 665-2310] (P-24), Collaborator from Imperial College, London

Modern laser-beam-smoothing techniques, known as random phase plates plus smoothing with spectral dispersion (RPP / SSD), are incapable of adequate early-time smoothing for ICF capsules. RPP / SSD provides adequate smoothing after a few hundred picoseconds, but no smoothing technique currently in use is able to create 1 to 2% rms uniformity beams very early in the implosion. The imprint created by nonuniform beams within the first 10 to 20 ps of the implosion will launch a nonuniform shock in the solid target, which will become Rayleigh-Taylor unstable upon breakout on the inner surface of the capsule regardless of the subsequently smooth beams. To remedy this problem, a plasma layer can be created between the absorption and ablation surfaces from time zero by using an x-ray preformed plasma produced from an initially low-density foam located between the solid capsule surface and the incident laser. The separation between the absorption and ablation layers allows efficient thermal smoothing of the initial imprint before energy is deposited into the shock, which is launched at the ablation surface. A series of experiments at the Los Alamos Trident Facility demonstrate the ability of the x-ray preheated low-density foam to completely eliminate the breakup observed after 1 ns resulting from the speckle pattern of an RPP without bandwidth (i.e., very much the worst case). If further work confirms the effect, a possible cure to the early-time imprint problem that could be catastrophic for ICF may have been found.

Application of Plasma Technologies to the Surety of Nuclear Weapons

B. P. Wood [(505) 665-6524] (P-24), K. C. Walter, C. P. Scherer (MST-4), R. J. Faehl (X-5), T. H. Allen (NMT-5)

We are merging an erbium cathodic arc with our existing PSII Facility to deposit very adherent erbia (Er_20_3) films. In a cathodic arc, a 100- to 200-A arc is drawn between a coaxial anode and cathode, causing the ejection of a plasma plume of the cathode material. This plume can be used to deposit metal or diamond-like carbon films on a substrate. Pulse biasing the substrate has been shown to greatly increase the adherence of ceramic metal-oxide films deposited by operating the cathodic arc in a backfill of 0_2. These films will serve as a base for an existing process to improve the adherence of ceramic films used to provide fire resistance for nuclear-weapons components. Separately, we are investigating the use of our cathodic arc to deposit films of various hard and refractory metals (chromium, titanium, tungsten) and diamond-like carbon for applications that require corrosion and wear resistance.

Tokamak Disruption Studies and Control Program

G. A. Wurden [(505) 667-5633], C. W. Barnes, R. Bartsch, W. A. Reass, H. Alvestad, T. Ortiz (P-24), J. Finn, D. C. Barnes, R. Gerwin, A. Glasser, R. Nebel (T-15)

We have recently focused Los Alamos efforts in large-tokamak magnetic-fusion experiments to understand and control the phenomenon of “disruptions” in tokamaks. The term “disruption” refers to the sudden and catastrophic loss of plasma current in the tokamak configuration. The confinement of the plasma is lost; a large flux of energy and particles damage the walls of the vessel, and large transient magnetic forces damage the vessel components. Because the energy losses are on an order of 10 MJ on 1-ms timescales in present tokamaks, the events can be very damaging indeed. Our efforts will be to design a multimachine database of disruption characteristics from past and present tokamaks to aid in the design of larger next-generation tokamak devices. We are also building diagnostics aimed at detecting the fast, transient sequence of events leading up to disruptions. Researchers from Los Alamos are working with the Princeton University Tokamak Fusion Test Reactor and at the Massachusetts Institute of Technology Alcator C-MOD tokamak. In collaboration with Columbia University, we will be applying our expertise with high-power, high-voltage, and high-current supply systems to apply magnetic feedback control to stabilize some of the most virulent forms of the disruption on the HBT-EP tokamak in New York City. This effort is tied to state-of-the-art modeling and simulation using both analytic and sophisticated three-dimensional numerical techniques.

P-25: Subatomic Physics

Fermilab Experiment E789: Study of Two-Prong Decays of Neutral B and D Mesons; Fermilab Experiment E866: Measurement of $\bar{d}(x)/\bar{u}(x)$ in the Proton

J. G. Boissevain [(505) 667-6057], T. A. Carey, D. M. Jansen, J. S. Kapustinsky, D. W. Lane, M. J. Leitch, P. L. McGaughey, J. M. Moss, W. E. Sondheim, J.-C. Peng, G. T. Garvey, D. M. Lee, C. Morris (P-25), Collaborators from Abilene Christian University, University of Chicago, Fermi National Accelerator Laboratory, University of Illinois at Chicago, Lawrence Berkeley Laboratory, Northern Illinois University, University of South Carolina, and the Institute of Physics at Taiwan

Physicists from P-25 have played a leading role in the Fermilab E789 experiment, the original goal of which was to detect charmless B decays. The scope of the experiment has expanded to include new measurements of the nuclear dependence of J/Ψ and D-meson production. Approximately 4,000 $D \rightarrow K\pi$ and approximately 100 $B \rightarrow J/\Psi X$ events are estimated to have been collected during the July 1991 through January 1992 running period of the experiment. Those data, which are now being analyzed and published, are expected to lead to important results on the nuclear dependence of D-meson production and on the B-meson cross section at 800 GeV. New data on the A-dependence of J/Ψ production at negative x_F and very large x_F have been obtained. As part of their role in the experiment, the P-25 group took on the important responsibility of implementing a silicon-strip vertex detector to carry out the experiment. That detector was the first silicon-strip detector that had to operate in an experimental radiation environment similar to that expected of silicon detectors that were being built for experiments at the Superconducting Super Collider (SSC). The performance of this vertex detector was of considerable interest to teams working on the SSC and the Large Hadron Collider. The apparatus from this experiment will be used in the recently approved Fermilab E866 experiment where the Drell-Yan process will be used to probe the $\bar{d}(x)/\bar{u}(x)$ asymmetry in the proton. The possibility of a large $\bar{d}(x)/\bar{u}(x)$ asymmetry has recently been suggested as an explanation for the apparent violation of the Gottfried sum rule observed in deep inelastic-scattering experiments. During 1994, work progressed on the design and construction of new drift chambers for the upcoming E866 experiment, as well as analysis and publications of results from E789.

Neutral Meson Spectrometer

R. L. Boudrie [(505) 667-7324] (P-25)

To date, the most comprehensive existing data for $\pi^- p \rightarrow \pi^0$ cross sections near the Δ resonance are measurements reported in 1977 using a time-of-flight method to detect the outgoing neutron. These data when compared with the partial wave analyses (PWAs) of other groups are systematically higher than the PWAs at the back angles in the energy intervals that we explore. The neutral meson spectrometer was used in a recent experiment to detect the π^0 over the full angular range of 0° to 180° and over the energy interval around the Δ resonance. The data are under analysis, but the absolute cross sections are expected to be accurate to a few percent, providing stringent constraints on the PWAs. The isovector monopole (IVM) resonance has been previously identified in single charge exchange with the original π^0 spectrometer. However, the large width of 20 MeV can encompass the region of the giant quadrupole resonance and the spin-flip dipole resonance. Calculations using a microscopic pion distorted wave have shown that these resonances have distinctly different excitation functions. Measurements were taken on an ^{56}Fe target at three incident energies over 0° to 40° scattering angles. These data should provide insight into the confirmation and characterization of the IVM resonance.

MEGA

M. D. Cooper [(505) 667-2929] (P-25)

Researchers at Los Alamos are investigating new physics beyond the Standard Model by studying the rare decay of a muon into an electron and gamma ray in the MEGA [**M**uon (decays to) an **E**lectron and a **GA**mma ray] experiment. This reaction, which has not yet been observed, sets one of the most stringent limits on lepton-family-number conservation. Observation of this decay mode would provide evidence for physics beyond the minimal Standard Model. A 19-MHz muon beam is stopped at the center of the MEGA apparatus. The MEGA signal is a 52.8-MeV positron and a 52.8-MeV photon, which are back to back and in time coincidence. The detector has a large-area, multiple-layer pair spectrometer to detect photons and a set of high-rate multiwire proportional chambers to measure the positron energies. A combination of hardware and software filters reduces the rate of candidate events to 65 Hz. These measurements will be completed by the end of the FY95 running period at the LAMPF with the possibility of two additional months of running at the start of FY96. The experiment should set a limit of better than 10^{-12} on the branching ratio for this reaction (unless, of course, they observed the reaction).

Experiment NA44 at the European Center for Nuclear Research

B. V. Jacak [(505) 667-8121], J. G. Boissevain, D. E. Fields, M. J. Murray, M. Sarabura, J. E. Simon-Gillo, W. E. Sondheim, J. P. Sullivan, H. W. van Hecke (P-25), Collaborators from institutions in the U.S., Denmark, Germany, Switzerland, and Japan

Experiment NA44 at the European Center for Nuclear Research (CERN) is a second-generation, relativistic, heavy-ion experiment that focuses on distributions of identified charged particles at mid rapidity. The main thrust of the experiment is to study correlations among identical particles as a function of p_t to provide a closer look at the space-time extent of the central region of heavy-ion collisions. The experiment is unique at 200 GeV / nucleon in its ability to compare correlations of identified pions, kaons, and eventually protons. Comparison of pion and kaon results clarifies the effects of resonance decays versus the time evolution of the emitting source. The NA44 high statistics allows a careful study of the behavior of the (usually not well understood) chaoticity parameter and the exact shape of the correlation function. Members of the collaboration also interact with theoretical colleagues to study correlation functions predicted by the Relativistic Quantum Molecular Dynamics (RQMD) event generator and to compare those predictions with the NA44 data. This work has provided the first detailed explanation of the information contained in the shape of the correlation function. During 1994, CERN had the world's first-ever lead beams accelerated to relativistic energies, and NA44 took data. Those results are currently being analyzed in preparation for publications during 1995 along with other very interesting single-particle spectra and two-particle correlations.

The PHENIX Experiment at the Brookhaven National Laboratory Relativistic Heavy Ion Collider

B. V. Jacak [(505) 667-8121], J. G. Boissevain, T. A. Carey, D. E. Fields, M. J. Leitch, J. W. Lillberg, W. W. Kinnison, D. M. Lee, P. L. McGaughey, J. M. Moss, J. E. Simon-Gillo, W. E. Sondheim, J. P. Sullivan, H. W. van Hecke, L. S. Waters (P-25), A. Gavron (P-23), PHENIX Collaboration

Brookhaven National Laboratory's Relativistic Heavy Ion Collider (RHIC) project presents an opportunity to increase the $\sqrt{s}$ of relativistic heavy ion collisions by a factor of 10 over the highest available energy to date and to look at systems with much larger energy densities. We are actively involved in the PHENIX collaboration, which focuses on leptons, photons, and hadrons. We believe that lepton measurements provide the most promising approach at RHIC as the leptons leave the hot, dense system relatively undisturbed by the hadronization process and the surrounding matter. Careful study of *p*-nucleus collisions will allow us to quantify effects of cold nuclear matter while the extension to high-mass muon pairs allows a grounding of the results by quantum chromodynamics calculations in the q^2 region where they are understood. Our group has primary responsibility for both the silicon multiplicity and vertex detector subsystem, the muon arm subsystem of the experiment, and the on-line system. Several Los Alamos physicists serve on the detector and executive councils for PHENIX.

The L3 Experiment at the European Center for Nuclear Research

W. W. Kinnison [(505) 667-4504], J. G. Boissevain, T. E. Coan, J. S. Kapustinsky, M. Brooks (P-25), T. C. Thompson (ESA-8), the L3 Collaboration

Los Alamos has been a collaborator on the L3 experiment at the Large Electron-Positron Collider at CERN in Geneva, Switzerland, since 1990. Members of P-25 and other organizations at Los Alamos and elsewhere have built and installed a new silicon-microvertex detector (SMD) into the L3 detector. The SMD, which has two tracking layers and is 30 cm long and 15 cm in diameter, improves the vertex-finding capability of L3 to about a 20-µm impact-parameter resolution and with about a 30% improvement in the momentum resolution for charged particles. The SMD also greatly improves the z-position resolution for charged particles. The primary purpose of the SMD was to ensure that L3 would be in a position to improve upon the limits on the Higgs mass when the beam energy of the machine goes up to 200 GeV $\sqrt{s}$ in 1996. In the meantime, Los Alamos has played a role in contributing to an aggressive program of B-meson and τ-lepton physics.

Liquid Scintillator Neutrino Detector

W. C. Louis [(505) 667-6723], D. H. White, F. J. Federspiel, V. D. Sandberg (P-25), R. D. Bolton (NIS-6), J. B. Donahue (AOT-7), G. T. Garvey (DSTBT), M. Schillaci (ESH-12), Collaborators from Brookhaven National Laboratory, the University of California at Riverside, the University of California at San Diego, the University of California at Santa Barbara, the University of California Intercampus Institute for Research at Particle Accelerators, Embry Riddle Aeronautical University, Linfield College, Louisiana State University, Louisiana Tech University, University of New Mexico, Southern University, and Temple University

Neutrino mass is a central issue for particle physics because neutrinos are massless in the Standard Model and for cosmology because relic neutrinos, if massive, would have profound effects on the structure of the universe. Researchers involved in the Liquid Scintillator Neutrino Detector (LSND) experiment have published evidence for neutrino oscillations and are trying to identify the strange quark contribution to the proton's spin by measuring neutrino-proton elastic scattering. Researchers at Los Alamos plan to run the experiment for several more years to lend statistical weight to their results and to further analyze possible sources of spurious signals. The LSND was commissioned during the summer of 1993. It had an initial 1.5-month run in the fall of 1993 and a longer 3.5 month run in 1994. Protons from the LAMPF 800-MeV linear accelerator produce pions in a 30-cm-long water target positioned about 1-m upstream from the copper beam stop. The beam stop provides a source of muon $\bar{\nu}$ via $\pi^+ \to \mu^+\nu_\mu$ followed by $\mu^+ \to e^+\nu_e\bar{\nu}_\mu$. Observation of $\bar{\nu}_e$ above background may be interpreted as evidence for neutrino oscillations (hence mass) or some direct lepton-number violating process. The definitive experimental establishment of nonzero neutrino mass will have a far-ranging impact into other fields such as astrophysics. Present evidence suggests a strong need for follow-up experiments at the Fermi National Accelerator Laboratory.

High-Energy Pion Research

C. L. Morris [(505) 667-5652], J. D. Zumbro (P-25)

A major part of the pion-nucleus total cross section is quasi-free (QF) scattering, which contains most of the inelastic cross section. High-energy pions provide an interesting probe of QF processes because of their long mean-free path and consequent access to the center of the nucleus. Inclusive spectra for pion-nucleus inelastic scattering at the energy loss associated with π-N scattering and a peak at lower energies (called the Δ peak) are presumably associated with pion production. The region between the QF peak and the Δ peak, called the dip region, has been extensively studied in inelastic electron scattering. The pion spectra display a feature in common with inelastic electron spectra taken at similar momentum transfer: a filling in of the dip region in comparison with expectations based on simple models. In FY94, new measurements were made at a higher energy (574 MeV) to determine the cause of the filling in of the dip. Preliminary results clearly demonstrate that the effect is fixed in outgoing pion energy. This strongly suggests that the fault lies in the assumptions built into the pion transport, not in the nuclear response. The comparison between the data in the dip region and the cascade predictions points to the need for a mechanism that makes the nucleus transparent to pions at central nuclear densities with energies near the Δ resonance. In the 1960s, theoretical investigations first suggested nucleon resonances might play a role in nuclear structure. Although calculations have suggested that virtual Δ's should exist in the nuclear wave function at the few percent level, they have proved difficult to detect despite significant experimental effort. A measurement of these wave function components would provide important constraints on models of nuclear binding and on the nature of short-range interactions in the nuclear medium. We recently reported a more general method of measuring Δ wave function components using the reaction $(\pi^+,\pi^- p)$ as a probe to search for Δ^-'s in nuclei. If one allows pionic and delta degrees of freedom in the nucleus, features in the outgoing pion energy spectrum emerge. The spectrum is expected to show the QF signature of two-body scattering, *i.e.*, a broad peak near $\varpi = q^2/2m$, where ϖ is the energy loss in the reaction, q is the momentum transfer, and m is the mass of the recoiling particle. During the LAMPF experiment E1285, a new system using two magnetic spectrometers in coincidence to detect scattered pions and recoil protons was commissioned to verify and extend the previous measurements. This system has been used to take new data on the isotopic sequence $^{12,13,14}C$. Preliminary analysis of the data confirms the previous measurements on ^{12}C and provides new measurements for $^{13,14}C$. These new results suggest that the role of two-step processes through the intermediate analog state is small and confirm the conclusion that the cross section is due to double charge exchange on Δ^- wave function components.

Education Outreach: The Ring of Light Project

A. P. T. Palounek [(505) 665-2574] (P-25)

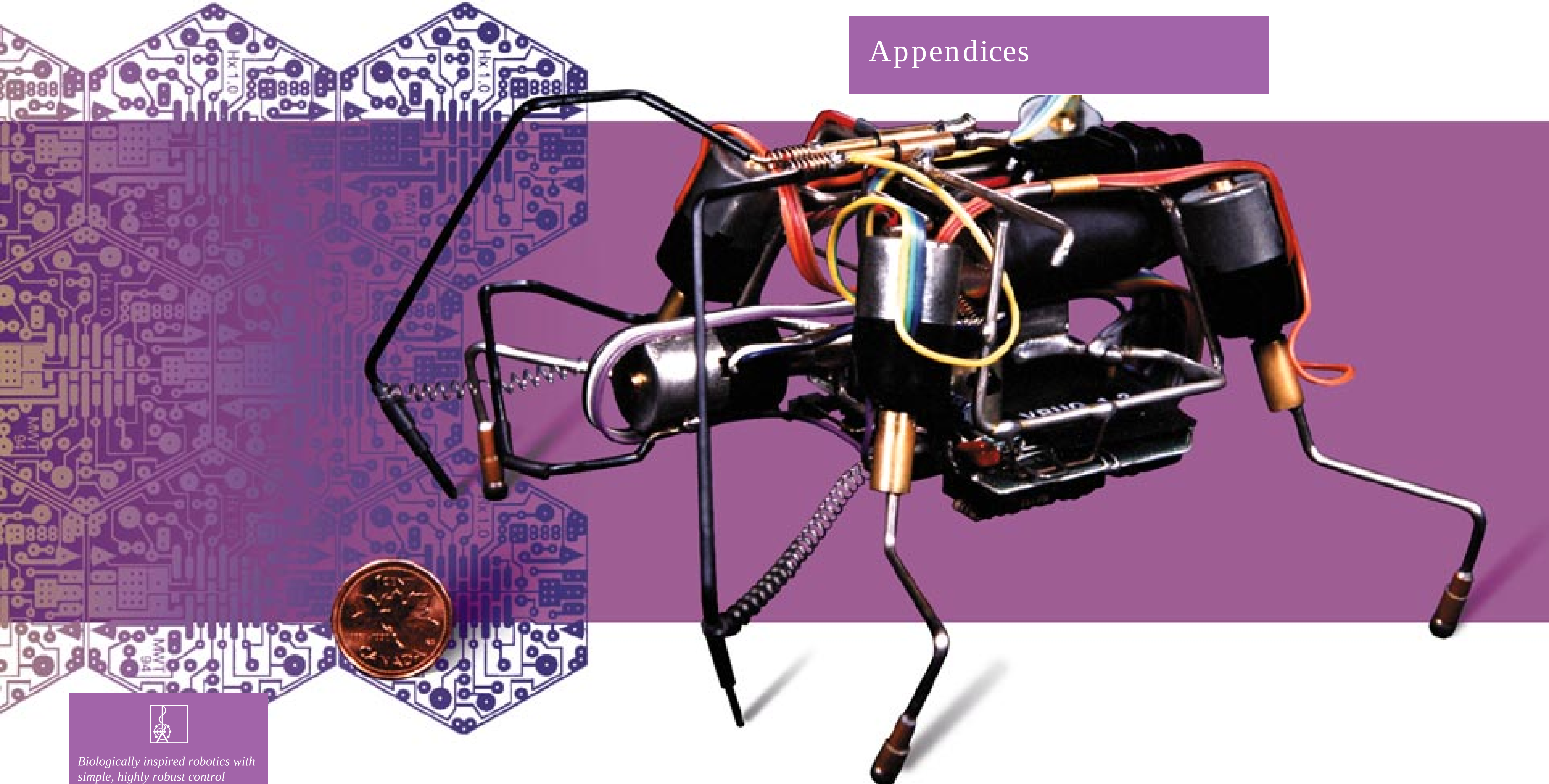
On Tuesday, May 10, 1994, an annular eclipse of the sun entered the U.S. at Sunland Park, New Mexico, and exited North America at the southern tip of Maine. Theories predict, and some earlier experiments indicate, that eclipses are associated with a bow shock or some other form of atmospheric disturbance. Getting a large array of sensors and measurements is difficult; previous experiments have made measurements at only a few locations. For the Ring of Light Project, middle school students and their teachers made the first widely distributed measurements of surface barometric pressure variations, wind speed and direction, temperature, and insolation (**In**coming **Sol**ar Radi**ation**) over a large array of sensors in and around the path of annularity. This collection of measurements, still under analysis, will provide important insight to further our understanding of atmospheric dynamics. The Ring of Light Project was the first time that science classes from schools with a wide geographic distribution used a computer network to collaborate in a scientific experiment of genuine interest. This project is a prototype for an exciting and compelling use of the information highway.

Atomic Parity Nonconservation Experiment

D. Tupa [(505) 665-1820], V. D. Sandberg (P-25), R. Guckert, D. J. Vieira, J. M. Wouters (CST-11), Collaborator from the University of Colorado

A measurement of the parity nonconserving component of the 6s-7s transition in different isotopes of atomic cesium can be used as a high precision test of the Standard Model and to investigate higher-order processes. A collaboration of researchers from P-25, CST-11, and the University of Colorado has made progress in several aspects of this experiment. Studies of a helium-jet target, which have been completed, demonstrate production rates of about 10^8 atoms per second of various cesium isotopes using the proton beam at LAMPF. A mass separator dedicated to the experiment is currently being assembled and will be used for studies of the accumulation and release of cesium from collector foils. The vacuum system, laser system, and trapping apparatus have been assembled and used to trap cesium atoms. A high-efficiency version of the trap is being built and integrated into the mass separator. Researchers from the University of Colorado have developed techniques to measure parity nonconserving amplitudes in stable cesium with an anticipated accuracy of 0.5%.

Appendices

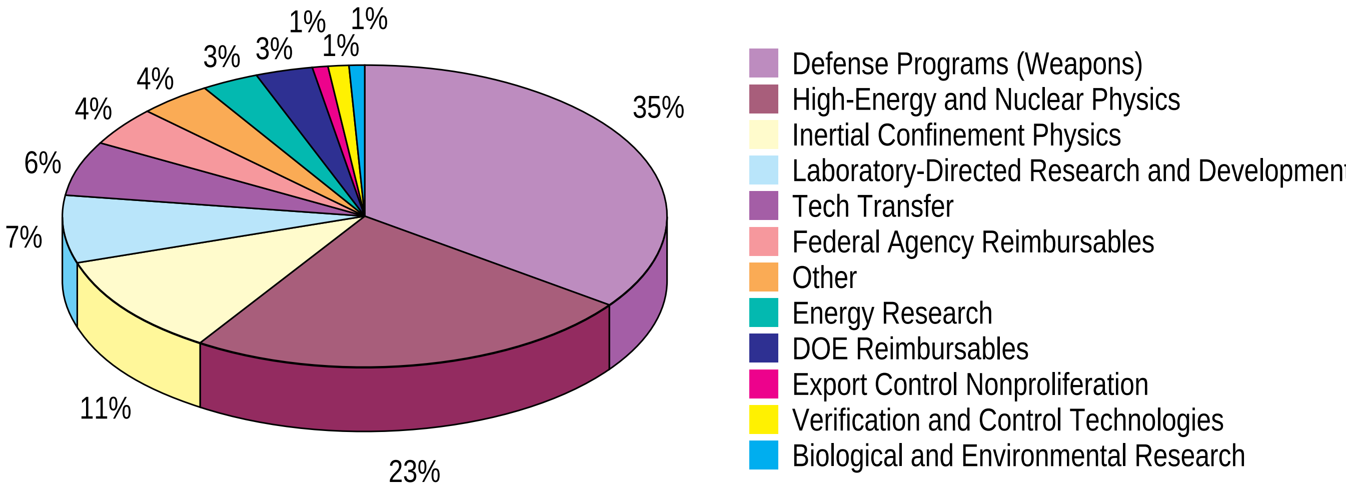


Biologically inspired robotics with simple, highly robust control circuits may contribute both to an improved understanding of robotic control and to a variety of applications in which reliable, inexpensive robotic capabilities are required.

Appendix A
Physics Division Data, FY94

Physics Division Groups: Principal Missions, Budgets, and Sizes

Group		
P-21: Biophysics	Costs:	$3.90 million
	Staff Members:	14.13 FTE
	Graded Employees:	6.21 FTE
P-22: Hydrodynamic and X-ray Physics	Costs:	$12.05 million
	Staff Members:	26.00 FTE
	Graded Employees:	24.00 FTE
P-23: Neutron Science and Technology	Costs:	$12.86 million
	Staff Members:	31.00 FTE
	Graded Employees:	22.91 FTE
P-24: Plasma Physics	Costs:	$12.04 million
	Staff Members:	29.68 FTE
	Graded Employees:	17.96 FTE
P-25: Subatomic Physics	Costs:	$12.12 million
	Staff Members:	35.20 FTE
	Graded Employees:	14.93 FTE



Expected Funding for Physics Division in 1995 = $53M.

Appendix B
Journal Articles, Presentations, Conference Proceedings, Books and Book Chapters

Journal Articles (1993)

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K. S. Bradley, J. C. Fernandez, P. Drake, J. DeGroot, and S. H. Batha, "Toward Understanding SBS in Laser-Produced Plasmas," APS Division of Plasma Physics 35th Annual Meeting, St. Louis, Missouri, November 1-5, 1993.

S. E. Caldwell, "Colliding Plasmas," APS Division of Plasma Physics Annual Meeting, St. Louis, Missouri, November 1-5, 1993.

S. E. Caldwell, "Modeling Trident Colliding Plasma Experiments, APS Meeting, St. Louis, Missouri, June 25, 1993.

S. E. Caldwell, "Trident Colliding Plasma Experiments," Atomic Nuclear Effects Meeting, Santa Barbara, California, July 14, 1993.

J. Canada, R. E. Chrien, C. Ekdahl, P. J. Rodriguez, R. C. Smith, and G. L. Stradling, "Plasma Formation Experiments Relevant to Magnetized Target Fusion," High Power Particle Beams Meeting, San Diego, California, and IEEE / Plasma Science Meeting, Santa Fe, New Mexico, November 22, 1993.

B. E. Carlsten, M. J. Schmitt, E. J. Pitcher, P. G. O'Shea, and M. D. Wilke, "Emittance Measurements Using Quadrupole Scans for Photoinjector Driven Accelerators," 1993 Particle Accelerator Conference, Accelerator Science and Technology, Washington, D.C., May 17-20, 1993.

R. E. Chrien and D. B. Harris, "Neutron Time-of-Flight Ion Temperature Diagnostic for Nova," 1993 Topical Conference on the Physics of Radiatively Driven Inertial Confinement Fusion Targets, Monterey, California, April 26-29, 1993.

R. E. Chrien, G. A. Wurden, W. C. Sailor, and C. W. Barnes, "An Energy-Selective Fast Neutron Detector Based on Scintillating Fibers," APS Division of Plasma Physics 35th Annual Meeting, St. Louis, Missouri, November 1-5, 1993.

R. E. Chrien, "Recent Progress with a 500-KJ Plasma Focus," IEEE / Plasma Science Meeting, Vancouver, British Columbia, February 2, 1993.

R. E. Chrien, "ICF Experimental Research at Los Alamos National Laboratories," 22nd ECLIM Meeting, Paris, France, February 25, 1993.

R. E. Chrien, "Initial Operation of the Neutron Time-of-Flight Ion Temperature Diagnostic for Nova," Physics of Radiatively Driven ICF Targets Meeting, Monterey, California, March 19, 1993.

R. E. Chrien, "ICF Experimental Research at Los Alamos National Laboratory," Laser-Matter Interaction Meeting, Paris, France, May 14, 1993.

R. E. Chrien, "Mesonic Y-Scaling," APS Meeting, Pacific Grove, California, June 25, 1993.

J. A. Cobble, J. A. Oertel, and R. G. Watt, "Spectrally Resolved Gated X-ray Imaging," APS Division of Plasma Physics 35th Annual Meeting, St. Louis, Missouri, November 1-5, 1993.

B. J. Cooke, K. S. Lackner, D. H. Sharp, and H.-J. Ziock, "SSC Silicon-Tracker Read-Out Architecture," IEEE Nuclear Science Symposium, San Francisco, California, November 1993.

M. D. Cooper, "Searching for $\mu^+ \rightarrow e^+\gamma$," TRIUMF Users Group Meeting, Brookhaven National Laboratory Colloquium, Upton, New York, December 1993.

M. D. Cooper, W. Eichinger, P. Forman, and C. Lebeda, "High Resolution Water Vapor and Aerosol Properties of the Marine Troposphere from Lidar Observations," American Geophysical Union, San Francisco, California, December 6-10, 1993.

M. D. Cooper, "$\mu^+ \rightarrow e^+\gamma$," Muon Science Workshop, Santa Fe, New Mexico, April 5, 1993.

K. Croasdell, "Recording Reaction History with Digital Systems," NEDPC-93, 9th Biennial Nuclear Explosives Design Physics Conference, Lawrence Livermore National Laboratory, Livermore, California, November 8-12, 1993.

C. G. Davis, "Computational Astrophysics: Pulsating Stars," 2nd International Conference on Computational Physics, Beijing, China, September 13-17, 1993.

C. G. Davis, "Seismic Signals from Asymmetric Underground Nuclear Explosions," 2nd International Conference on Computational Physics, Beijing, China, September 13-17, 1993.

N. D. Delamater, G. Magelssen, and A. Hauer, "Re-emission Ball Technique for Symmetry Measurements," APS Division of Plasma Physics 35th Annual Meeting, St. Louis, Missouri, November 1-5, 1993.

N. D. Delamater and D. B. Harris, "Basic Image Analysis for Nova Symmetry Experiments," 1993 Topical Conference on the Physics of Radiatively Driven Inertial Confinement Fusion Targets, Monterey, California, April 26-29, 1993.

A. E. Feldman, J. Rapaport, C. Elster, B. Barmore, G. Fink, X. Yang, F. P. Brady, J. L. Romero, D. S. Sorenson, J. L. Ullmann, A. Ling, B. K. Park, C. R. Howell, and W. Tornow, "Backward Angle n-p Differential Cross Sections for $65 < E_n < 250$ MeV," APS Meeting, Washington, D.C., April 12-15, 1993.

J. C. Fernandez, R. R. Berggren, and M. D. Wilke, "Imaging Diagnostic for Backscattered Light from Nova Targets," APS Division of Plasma Physics 35th Annual Meeting, St. Louis, Missouri, November 1-5, 1993.

J. C. Fernandez, J. A. Cobble, and D. S. Montgomery, "Brillouin Scattering Measurements Hohlraums," 1993 Topical Conference on the Physics of Radiatively Driven Inertial Confinement Fusion Targets, Monterey, California, April 26-29, 1993.

E. R. Flynn, “Comparing Instrumental EEG Resolving Power by a Chi-Square Approach,” 9th International Conference on Biomagnetism, Vienna, Austria, August 14-20, 1993.

P. R. Forman, L. D. Looney, and L. J. Tabaka, “Fiber-Optic Currents Measurements,” 13th European Symposium / Optoelectronics (OPTO ’93), Paris, France, February 2, 1993.

P. R. Forman, M. Y. Hockaday, and R. G. Hockaday, “Direct Drive Foil Implosion Experiments on Pegasus II,” Dense z-Pinches Meeting, London, England, April 16, 1993.

P. R. Forman, “Development and Use of a Ship-Borne Water Vapor Raman Lidar for Use in Ocean-Atmosphere Research,” Laser Radar and Lidar Conference, Lake Tahoe, California, July 27, 1993.

P. R. Forman, “Polarization Effects in Optical Fiber Current Sensors Based on SAGNAC Interferometers with 3 x 3 Couplers,” Optical Fiber Sensors Meeting, Florence, Italy, April 15, 1993.

P. R. Forman, “Fiber z-Pinch Instabilities,” 3rd International Conference on Dense z-Pinches, London, England, April 21, 1993.

P. R. Forman, “Plasma Flow Switch and Foil Implosion Experiments on Pegasus II,” IEEE International Pulsed Power Conference, Albuquerque, New Mexico, June 23, 1993.

P. R. Forman, “CEPEX Atlas of Cirrus Clouds from the Elastic Backscatter Lidar Mounted Aboard the R. V. Vickers,” CEPEX Coordinating Team Meeting, San Diego, California, July 27, 1993.

H. Frauenfelder, “What Can Physics Learn from Biology?” The Emil Warburg Lectures, University of Bayreuth, Bayreuth, Germany, June 1993.

H. Frauenfelder, “Concepts in Protein Dynamics,” 11th International Biophysics Congress, Budapest, Hungary, July 1993.

H. Frauenfelder, “Physics from Proteins,” 1st International Symposium on Biological Physics, Szeged, Hungary, July 1993.

H. Frauenfelder, “The Mössbauer Effect and Biological Physics,” International Conference on Applications of the Mössbauer Effect, Vancouver, Canada, August 1993.

R. D. Fulton, P. J. Adamas, G. A. Kyrala, G. L. Olson, G. T. Schappert, and A. J. Taylor, “Stability of Propagation of Strong Shocks at Solid Density,” 11th International Workshop on Laser Interactions and Related Plasma Phenomena, Monterey, California, October 25-29, 1993.

G. T. Garvey, “The Neutral Current Axial Vector Form Factor of the Nucleon,” Particles and Nuclei International Conference, Perugia, Italy, June 28–July 2, 1993.

A. Gavron and J. P. Lestone, “Determination of the Fission Cross Section of ^{237}U,” Nuclear Explosives Physics Design Conference (NEDPC), Livermore, California, November 8-12, 1993.

J. S. George, P. S. Lewis, H. A. Schlitt, L. Kaplan, I. Gorodnitsky, and C. C. Wood, “Strategies for Source Space Limitation in Tomographic Inverse Procedures,” 9th International Conference on Biomagnetism, Vienna, Austria, August 14-20, 1993.

J. S. George, J. S. Sanders, J. D. Lewine, A. Caprihan, and C. J. Aine, “Comparative Studies of Brain Activation with MEG and Functional MRI,” 9th International Conference on Biomagnetism, Vienna, Austria, August 14-20, 1993.

J. H. Goforth, H. Oona, D. T. Torres, A. E. Greene, W. E. Anderson, R. L. Bowers, J. H. Brownell, R. E. Chrien, C. M. Fowler, I. R. Lindemuth, C. M. Lund, S. P. Marsh, O. F. Garcia, J. C. King, T. Oliphant, J. V. Parker, R. E. Reinovsky, J. S. Shlacter, L. R. Veeser, D. L. Weiss, F. J. Wysocki, N. F. Roderick, P. J. Turchi, D. H. Herrera, B. G. Anderson, J. C. Cochrane, and L. J. Tabaka, “Review of the Procyon Explosive Pulsed Power System,” 9th IEEE International Pulsed Power Conference, Albuquerque, New Mexico, May 19, 1993, and June 21-23, 1993.

T. J. Goldman, R. E. Brown, J. B. Camp, T. Darling, P. Dyer, M. H. Holzscheiter, R. J. Hughes, N. Jarmie, N. S. P. King, D. C. Lizon, M. M. Nieto, M. M. Schauer, J. A. Schecker, S. Cornford, K. Hosea, R. A. Kenefick, S. Hoeibraaten, M. M. Midzor, S. P. Parry, and R. A. Ristinen, “Beyond Metric Gravity: Progress on PS-200,” Workshop on Traps for Antimatter and Radioactive Nuclei, Vancouver, Canada, February 25-27, 1993.

R. J. Goldstone, G. A. Wurden *et al.*, “The Mission and Physics Design of TPX,” 1993 European Physical Society Meeting, Lisbon, Portugal, 1993.

R. Greegor, D. Dowell, D. Smith, M. D. Wilke, J. D. Gilpatrick, D. B. Barlow, R. E. Meyer, and A. Valla, “Electron-Beam Diagnostics for the Average Power Laser Experiment: High Power Oscillator (APLE/HPO),” 15th International Free-Electron Laser Conference, The Haque, Netherlands, August 23-27, 1993.

D. B. Harris and R. E. Chrien, “Measurement of ICF Fuel Ion Temperature on Nova,” Conference on Laser Interaction and Related Plasma Phenomena, Monterey, California, October 1993.

A. Hauer, N. D. Delamater, W. W. Hsing, D. B. Ress, L. J. Suter, L. V. Powers, D. B. Harris, O. L. Landen, A. P. Thiessen, D. W. Phillion, P. A. Amendt, G. R. Magelssen, R. G. Watt, and B. A. Hammel, “Review of Drive Symmetry Measurement and Control,” APS Division of Plasma Physics 35th Annual Meeting, St. Louis, Missouri, November 1-5, 1993.

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L. Heller, R. Aaron, E. D. Best, H. A. Schlitt, and D. M. Ranken, "Mesh Generation Issues in the EEG and MEG Forward Problems," 9th International Conference on Biomagnetism, Vienna, Austria, August 14-20, 1993.

M. Y. Hockaday, R. E. Chrien, R. R. Bartsch, J. C. Cochrane, J. S. Ladish, H. Oona, J. V. Parker, D. Platts, L. R. Veeser, R. Walton, R. L. Bowers, H. Lee, A. J. Scannapieco, and W. Anderson, "Overview of Weapons Physics Experiments in Athena: Liner," NEDPC-93, 9th Biennial Nuclear Explosives Design Physics Conference, Lawrence Livermore National Laboratory, Livermore, California, November 8-12, 1993.

M. Y. Hockaday, "Nova Crack Experiment," Physics of Radiatively Driven ICF Targets Meeting, Monterey, California, March 30, 1993.

R. G. Hockaday, "Modeling and Characterizing X-ray Output from Pulsed Power Experiments for AGEX Applications," Nuclear Explosives Design Physics Conference, Livermore, California, November 8, 1993.

M. H. Holzscheiter, "Trapping of Antiprotons: A First Step on the Way to Antihydrogen," Workshop on Traps for Antimatter and Radioactive Nuclei, Vancouver, Canada, February 25-27, 1993.

W. W. Hsing, J. M. Wallace, B. H. Wilde, P. G. Apen, K. G. Estabrook, J. D. Porter, and L. E. Ruggles, "Long Scale-Length Plasmas Created with Low Density Foams," APS Division of Plasma Physics 35th Annual Meeting, St. Louis, Missouri, November 1-5, 1993.

W. W. Hsing, T. A. Archuleta, J. A. Cobble, N. D. Delameter, S. C. Evans, J. C. Fernandez, A. Hauer, T. R. Hurry, J. L. Jimerson, J. M. Mack, J. A. Oertel, T. J. Sedillo, R. G. Watt, R. B. Gibson, and R. E. Chrien, "ICF Experimental Research at Los Alamos National Laboratory," 22nd European Conference on Laser-Matter Interaction, Paris, France, May 10-14, 1993.

W. W. Hsing, N. Hoffman, G. R. Magelssen, N. D. Delamater, and A. Hauer, "Cylindrical Implosions on Nova," 1993 Topical Conference on the Physics of Radiatively Driven Inertial Confinement Fusion Targets, Monterey, California, April 26-29, 1993.

W. W. Hsing, N. D. Delameter, A. Hauer, B. A. Hammel, O. L. Landen, B. Remington, D. B. Ress, and T. Weiland, "Short Pulse Backlighting on Nova," 22nd European Conference on Laser-Matter Interaction, Paris, France, May 10-14, 1993.

R. J. Hughes, "Two Problems in Quantum Mechanics: Feynman's Proof of the Maxwell Equations, and New Test of the Equivalence Principle for Neutral Kaons and the Antiproton," Rice University, Houston, Texas, February 1993; University of Bergen, Bergen, Norway, April 1993; University of Århus, Århus, Denmark, April 1993; and Niels Bohr Institute, Copenhagen, Denmark, May 1993.

R. J. Hughes, “Antihydrogen and Fundamental Symmetries,” Colloquium at Rice University, Houston, Texas, February 1993; Physics Institute, University of Oslo, Norway, April 1993; and Ecole Normale Superieure, Paris, France, May 1993.

R. J. Hughes, “Fundamental Symmetries and Precision Measurements on Trapped Particles,” Workshop on Traps for Antimatter and Radioactive Nuclei, TRIUMF, Vancouver, Canada, February 25-27, 1993; Department of Physics and Astronomy, University of Århus, Århus, Denmark, April 1993; and University of Stockholm, Stockholm, Sweden, April 1993.

R. J. Hughes, “Does Antimatter Fall with the Same Acceleration as Matter?” Theoretical Physics Seminar, University of Oslo, Norway, April 1993.

R. J. Hughes, “Feynman’s Proof of the Maxwell Equations,” Theoretical Physics, University of Oslo, Norway, May 1993.

R. J. Hughes, “Quantum Cryptography,” National Security Agency Meeting, Fort Meade, Maryland, September 1993.

G. C. Idzorek, R. G. Hockaday, C. Gallegos, and J. M. Gonzales, “United States / Russian Angara-5 z-Pinch Spectra,” NEDPC-93, 9th Biennial Nuclear Explosives Design Physics Conference, Lawrence Livermore National Laboratory, Livermore, California, November 8-12, 1993.

B. V. Jacak, “Antiproton Production in Heavy Ion Collisions,” NATO Hot and Dense Nuclear Matter, Bodrum, Turkey, October 5, 1993.

B. V. Jacak, “The Experimental Program at RHIC,” Conference on Perspectives of QCD and Nuclear Physics Studies at Multi-GeV Hadron Facilities, Los Alamos, New Mexico, June 1993.

D. M. Jansen, J. Boissevain, T. A. Carey, R. G. Jeppesen, J. S. Kapustinsky, D. W. Lane, M. J. Leitch, J. W. Lillberg, P. L. McGaughey, J. M. Moss, J. C. Peng, G. Brown, L. D. Isenhower, J. Keyser, M. E. Sadler, R. Schnathorst, R. Schwindt, G. Gidal, P. M. Ho, M. S. I. Kowitt, K. B. Luk, D. Pripstein, L. M. Lederman, M. H. Schub, C. N. Brown, W. E. Cooper, H. D. Glass, K. N. Gounder, C. S. Mishra, D. M. Kaplan, W. R. Luebke, V. M. Martin, R. S. Preston, J. Sa, V. Tanikella, R. Childers, C. W. Darden, D. Snodgrass, J. R. Wilson, Y. C. Chen, G. C. Kiang, and P. K. Teng, “Beauty and Charm Production from Fermilab Experiment E789,” 28th Rencontres de Moriond QCD and High-Energy Hadronic Interactions, Les Arcs, Savoie, France, March 20-27, 1993.

J. S. Kapustinsky, “The Design and Construction of a Double-Sided Silicon Microvertex Detector for the L3 Experiment at CERN,” IEEE 1993 Nuclear Science Symposium, San Francisco, California, October 30–November 6, 1993.

G. Katul, M. Parlange, and W. Eichinger, “The Statistical Structure of the Atmospheric Surface Layer from Lidar Measurements of Humidity,” Fall Meeting of the American Geophysical Union, San Francisco, California, December 6-10, 1993.

N. S. P. King, K. L. Albright, T. E. McDonald, G. J. Yates, and B. T. Turko, "High-Frame Rate CCD Cameras with Fast Optical Shutters for Mine Detection and Surveillance Applications," Imaging and Technology Conference and Exposition, Items '93, Washington, D.C., June 1993.

P. E. Koehler, F. Kappeler, H. Schatz, Yu. M. Gledenov, Yu. P. Popov, J. A. Harvey, N. W. Hill, M. Wiescher, R. W. Kavanagh, and R. B. Vogelaar, "Recent Results in Explosive and S-Process Nucleosynthesis from Measurements on Radioactive and Stable Targets," 8th International Symposium on Capture Gamma-Ray Spectroscopy and Related Topics, Fribourg, Switzerland, September 20-24, 1993.

G. A. Kyrala, R. D. Fulton, and G. T. Schappert, "Non-Linear Interactions of Laser-Generated X-rays," OSA Proceedings on Short Wavelength V (93), San Diego, California, March 29-31, 1993.

G. A. Kyrala, A. J. Taylor, J. P. Roberts, G. Rodriguez, R. D. Fulton, and G. T. Schappert, "Short-Pulse, High-Intensity Lasers at Los Alamos," 11th International Workshop on Laser Interactions and Related Plasma Phenomena, Monterey, California, October 25-29, 1993.

J. P. Lestone and A. Gavron, "Neutron-Induced Fission of U Isotopes up to 100 MeV," 12th Meeting of Physics of Nuclear Fission, Institute of Physics and Power Engineering, Obninsk, Kaluga Region, Russia, September 27-30, 1993.

J. D. Lewine, J. S. George, E. R. Flynn, J. A. Sanders, R. S. Astur, and C. C. Wood, "Comparison of MEG, EEG, and TEG Responses to Somatosensory Stimulation in the Monkey," 9th International Conference on Biomagnetism, Vienna, Austria, August 14-20, 1993.

F. Liu, "Measurement of the Michel Parameter ρ with the MEGA Positron Spectrometer," APS Spring Meeting, Washington, D.C., April 1993.

G. Luther, B. Warthen, and L. R. Veeser, "A Microwave Interferometer to Measure Transient Properties," INWET-93, DNA Conference on Instrumentation for Nuclear Weapons Effects Testing, Menlo Park, California, November 2-5, 1993.

W. Matuska, B. DeVolder, G. Idzorek, and H. Lee, "The Fluorescer Experiment on Pegasus," NEDPC-93, 9th Biennial Nuclear Explosives Design Physics Conference, Lawrence Livermore National Laboratory, Livermore, California, November 8-12, 1993.

D. Mayo, "Initial Results from the LAMPF Neutron-Proton Bremsstrahlung Experiment," DNP Meeting 1993, Asilomar, California, October 1993.

J. B. McClelland, T. A. Carey, L. J. Rybarcyk, W. C. Sailor, T. N. Taddeucci, X. Y. Chen, D. J. Mercer, S. Delucia, B. Luther, D. G. Marchlenski, E. R. Sugarbaker, J. Rapaport, E. Gulmez, C. Whitten, Jr., C. D. Goodman, Y. Wang, and W. P. Alford, "Polarization Transfer Measurements in the Quasi-Free (p,n) Reaction at 495 MeV: Probing the Pionic Field of the Nucleus," 13th Particles and Nuclei International Conference, Perugia, Italy, June 1993.

T. E. McDonald, "High-Speed Electronic Imaging at Los Alamos National Laboratory," Industry Tech '93 Conference, Kansas City, Missouri, May 1993.

T. E. McDonald, K. L. Albright, N. S. P. King, and G. J. Yates, "High-Speed Imaging of Blood Splatter Patterns," Imaging and Technology Conference and Exposition, Items '93, Washington, D.C., June 1993.

T. E. McDonald, K. L. Albright, N. S. P. King, and G. J. Yates, "High-Speed Electronic Imaging at Los Alamos National Laboratory," Electronic Imaging, Optics, and Photonics Workshop, Rochester, New York, November 9-10, 1993.

J. L. Merson and L. J. Rybarcyk, "Wider Availability of PARMILA and Recent Improvements to AT-6 PARMILA," Computational Accelerator Physics Conference '93, Pleasanton, California, February 22-26, 1993.

G. B. Mills, "The Front-End Electronics for the L3 Silicon Microvertex Detector," Electronics for Future Colliders Conference, Chestnut Ridge, New York, May 4-5, 1993.

G. B. Mills, "The GEM Silicon Tracking System," International Symposium on the Development and Applications of Semiconductor Tracking Detectors, Hiroshima, Japan, May 22-24, 1993.

C. L. Morris, J. M. O'Donnell, and J. D. Zumbro, "Pion Scattering at Energies Above the Δ Resonance," Meson-Nucleus Interactions Conference, Cracow, Poland, May 14-19, 1993.

J. C. Mosher, R. M. Leahy, and P. S. Lewis, "Biomagnetic Localization from Transient Quasi-Static Events," IEEE Acoustics, Speech, and Signal Processing Conference, Minneapolis, Minnesota, April 26-30, 1993.

J. C. Mosher, P. S. Lewis, R. M. Leahy, and M. E. Spencer, "Interpretation of the MEG-MUSIC Scan in Biomagnetic Source Localization," 9th International Conference on Biomagnetism, Vienna, Austria, August 14-20, 1993.

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T. Ortenburger, C. Chu, M. Parlange, and W. Eichinger, "On the Development of the Internal Boundary Layer," Fall Meeting of the American Geophysical Union, San Francisco, California, December 6-10, 1993.

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A. P. T. Palounek, “A Summary of the Workshop on Simulating Accelerator Radiation Environments,” International Conference on Monte Carlo Simulation in High-Energy and Nuclear Physics, Tallahassee, Florida, February 22-26, 1993.

A. P. T. Palounek, “Simulating the SDC Radiation Backgrounds and Activation,” International Conference on Monte Carlo Simulation in High-Energy and Nuclear Physics, Tallahassee, Florida, February 22-26, 1993.

J. C. Peng, “Hypernuclear Physics with a Neutral Meson Spectrometer,” Workshop of Future Directions in Particle and Nuclear Physics at Multi-GeV Hadron Facilities, Brookhaven National Laboratory, Upton, New York, March 4-6, 1993.

J. C. Peng, “Past, Present, and Future of Pi,Eta Experiments,” Workshop of Future Directions in Particle and Nuclear Physics at Multi-GeV Hadron Facilities, Brookhaven National Laboratory, Upton, New York, March 4-6, 1993.

J. C. Peng, “Dileptons from Protons on Nuclear Targets,” Conference on Perspectives of QCD and Nuclear Physics Studies at Multi-GeV Hadron Facilities, Los Alamos, New Mexico, June 1-5, 1993.

J. C. Peng, “Heavy Meson Production at Fermilab and RHIC,” Workshop on Meson-Nucleus Dynamics at Intermediate and High Energies, Argonne, Illinois, August 2-6, 1993.

J. C. Peng, “Pion-Induced Eta Meson Production on Deuterium,” 5th International Symposium on Meson-Nucleon Physics and the Structure of the Nucleon, Boulder, Colorado, September 6-10, 1993.

A. Picklesimer, “A Few Δ’s in a Few Few-Nucleon Systems,” 1993 Few-Body Gordon Conference: Dynamics of Simple Systems in Chemistry and Physics, Andover, New Hampshire, August 16-20, 1993.

J. A. Phillips, D. A. Baker, and L. Mann, “Does Chaos Exist in an Axisymmetric Model of a Reversed Field Pinch?” APS Division of Plasma Physics 35th Annual Meeting, St. Louis, Missouri, November 1-5, 1993.

D. J. Rej, “Thin Film Deposition with Intense Ion Beams,” IEEE International Conference on Plasma Science, Vancouver, Canada, June 1993.

D. J. Rej, “Magnetic Suppression of Secondary Electrons in PSII,” 1st International Workshop on Plasma Based Ion Implantation, Madison, Wisconsin, August 1993.

D. J. Rej, “Diamond-Like Carbon Deposition with Intense Ion Beams,” APS Division of Plasma Physics Annual Meeting, St. Louis, Missouri, November 1993.

D. J. Rej, “Materials Processing with Intense Ion Beams,” 6th International Workshop on the Atomic Physics for Ion-Driven Fusion, Santa Fe, New Mexico, November 1993.

D. J. Rej, “First Results from the LANL PSII Experiment,” Materials Research Society Meeting, Boston, Massachusetts, December 1993.

R. G. H. Robertson, “Neutral-Current Detection in the Sudbury Neutrino Observatory: Perspectives in Neutrinos, Atomic Physics, and Gravitation,” 13th Moriond Workshop, Villars-sur-Ollon, Switzerland, January 30–February 6, 1993.

R. G. H. Robertson, “Stalking the Sinister Solar Neutrino,” Symposium on Weak Interactions, Nuclear Astrophysics and Cosmology, Michigan State University, East Lansing, Michigan, June 4-5, 1993.

R. G. H. Robertson, “Neutrino Mass: A Status Report,” 14th International Workshop on Weak Interactions and Neutrinos, Seoul, Korea, July 19-24, 1993.

R. G. H. Robertson, “Real-Time Experiments: Survey of Kamiokande, SNO, and SuperKamiokande,” Workshop Frontiers of Neutrino Physics, APS/DNP Meeting, Asilomar, California, October 20, 1993.

R. G. H. Robertson, “Laboratory Measurements of Neutrino Mass and the Mysterious End,” Colloquium, University of Washington, Seattle, Washington, November 22, 1993.

G. T. Schappert, J. A. Cobble, R. D. Fulton, G. A. Kyrala, G. L. Olson, and A. J. Taylor, “X-ray Production with Subpicosecond Laser Pulses,” 11th International Workshop on Laser Interactions and Related Plasma Phenomena, Monterey, California, October 25-29, 1993.

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J. T. Scheuer, M. Tuszewski, M. R. Daw, I. Campbell, and B. K. Laurich, “Inductive Plasma Source for Thin Film Growth,” 46th Gaseous Electronics Conference, Montreal, Quebec, Canada, October 1993.

S. J. Seestrom, “Conference Summary,” International Workshop on Time Reversal Invariance and Parity Violation in Neutron Reactions, Dubna, Russia, May 1993.

S. J. Seestrom, “Time Reversal and Parity Violation,” International Workshop on Time Reversal Invariance and Parity Violation in Neutron Reactions, Dubna, Russia, May 1993.

S. C. Sherwood, D. Cooper, W. Eichinger, U. Schmid, J. Meywerk, and J. Schultz, “Measurement of Tropical Atmospheric CAPE in CEPEX,” Fall Meeting of the American Geophysical Union, San Francisco, California, December 6-10, 1993.

J. E. Simon-Gillo, “Low p_T Phenomena Observed in High-Energy Nuclear Collisions,” Quark Matter ‘93 10th International Conference on Ultra-Relativistic Nucleus-Nucleus Collisions, Borlange, Sweden, June 20-26, 1993.

J. E. Simon-Gillo, “Low p_T Phenomena in High-Energy Collisions,” Michigan State University, East Lansing, Michigan, December 4, 1993.

D. S. Sorenson, J. L. Ullmann, R. C. Haight, A. Ling, R. A. Lindgren, B. Clausen, J. Rapaport, B. K. Park, F. P. Brady, J. L. Romero, and C. Wuest, “The Energy Dependence of the Effective n-n Isovector Tensor Interaction Using the Stretched Transition from the 3^+ Ground State of ^{10}B to the 0^+ Ground State of ^{10}Be over the Energy Range of 50 to 250 MeV,” Fall Meeting of the APS Division of Nuclear Physics, Pacific Grove, California, October 20-23, 1993.

J. P. Sullivan, “Source Sizes from CERN Data,” Workshop on Meson Interferometry in Relativistic Heavy Ion Collisions, Brookhaven National Laboratory, Upton, New York, April 1993.

J. P. Sullivan, “Measured and Calculated Bose-Einstein Correlations,” Oregon State University, Corvallis, Oregon, June 2, 1993.

J. P. Sullivan, “Planned RHIC Experiments,” Oregon State University, Corvallis, Oregon, June 1, 1993.

S. Supek and C. J. Aine, “Evaluation of MUSIC-Based Initial Source Modeling Assumptions for Spatio-Temporal Fitting of Simulated Multi-Source Neuromagnetic Data,” 9th International Conference on Biomagnetism, Vienna, Austria, August 14-20, 1993.

T. N. Taddeucci, “Polarized Quasi-Elastic and Quasi-Delta (p,n) Reaction on Nuclei,” Workshop on Perspectives of QCD and Nuclear Physics Studies at Multi-GeV Hadron Facilities, Los Alamos, New Mexico, June 1-5, 1993.

M. Tuszewski *et al.*, “Plasma Density Measurements in a Magnetically Insulated Ion Diode,” 20th IEEE Conference on Plasma Science, Vancouver, Canada, June 7-9, 1993.

M. Tuszewski *et al*., “Plasma Immersion Ion Implantation for Semiconductor Thin Film Growth,” 1st International Workshop on Plasma Based Ion Implantation, Madison, Wisconsin, August 4-6, 1993.

H. van Hecke, “A Spot Imaging Cerenkov Counter,” 1st Workshop on RICH Detectors, Bari, Italy, June 1993.

L. R. Veeser and J. L. Stokes, “Fiber Optic Diagnostic for High Explosives,” INWET-93, DNA Conference on Instrumentation for Nuclear Weapons Effects Testing, Menlo Park, California, November 2-5, 1993.

L. R. Veeser, L. J. Tabaka, and T. L. Petersen, "Fiber Optic Position Measurement on an Imploding, Current-Driven Liner," 7th Photonics Conference, Menlo Park, California, November 4-5, 1993.

R. G. Watt, R. B. Gibson, J. M. Mack, N. K. Moncur, and R. P. Johnson, "Trident: A New 1-TW Laser," 22nd European Conference on Laser-Matter Interaction, Paris, France, May 10-14, 1993.

W. B. Wilson, E. D. Arthur, A. D. Gavron, L. L. Daemen, W. W. Kinnison, D. M. Lee, P. W. Lisowski, D. W. Muir, A. Palounek, R. T. Perry, E. J. Pitcher, R. E. Prael, G. J. Russell, T. R. England, C. A. Beard, L. N. Engel, D. C. George, H. G. Hughes, R. J. La Bauve, H. Lichtenstein, G. H. Sanders, L. Waters, P. G. Young, Jr., H.-J. Ziock, and C. D. Bowman, "Accelerator Transmutation Studies on Los Alamos with LAHET, MCNP, and Cinder '90," Simulating Accelerator Radiation Environments, Santa Fe, New Mexico, January 1993.

B. L. Wright, K. R. Alrick, and J. N. Fritz, "Measurement of Large Ground Motions with the ASM Gage," The Joint AIRAPT / APS Conference on High-Pressure Science and Technology, Colorado Springs, Colorado, June 28–July 2, 1993.

G. A. Wurden, S. Jardin, D. Monticello, and H. Neilson, "Disruption Control Strategies for TPX," United States / Japan Workshop on Physics Issues for Steady-State Tokamaks, Kyushu, Japan, June 29–July 2, 1993.

G. A. Wurden, S. Medley, T. Peebles, and P. West, "TPX Diagnostics," Workshop on Physics Issues for Steady-State Tokamaks, Kyushu, Japan, June 29–July 2, 1993.

G. J. Yates and K. A. Albright, "Multiport Solid-State Imager Characterization at Variable Pixel Rates," 1993 SPIE International Symposium on Optics, Imaging, and Instrumentation, San Diego, California, July 11-16, 1993.

Y.-F. Yen, "Study of Parity Violation in Compound Nuclei Using Polarized Epithermal Neutrons," International Symposium on Nuclear Structure Physics Today, Chung-Li, Taiwan, May 11-14, 1993.

Y. Zhang, "Current Results for $\mu \rightarrow e + \gamma$ Decay Search with the MEGA Experiment," APS Spring Meeting, Washington, D.C., April, 1993.

H.-J. Ziock *et al.*, "Temperature Dependence of the Radiation-Induced Change of Depletion Voltage in Silicon PIN Detectors," IEEE Nuclear Science Symposium, San Francisco, California, November 3, 1993.

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D. A. Baker, J. M. Finn, J. A. Phillips, and R. F. Gribble, "Possibility of a Reversed-Field Pinch with a Toroidally Symmetric Resistive Shell," APS Division of Plasma Physics 36th Annual Meeting, Minneapolis, Minnesota, July 7-11, 1994.

C. W. Barnes *et al.*, "Neutron Production and Detection on the TFTR Tokamak During D-T Operation," 21st IEEE International Conference on Plasma Science, Santa Fe, New Mexico, June 6-8, 1994.

C. W. Barnes, A. R. Larson, G. L. Lemunyan, and M. J. Loughlin, "Measurements of DT and DD Neutron Yields by Neutron Activation on the Tokamak Fusion Test Reactor," 10th Topical Conference on High-Temperature Plasma Diagnostics, Rochester, New York, May 1994.

R. J. Bartlett, "4f Heavy Fermion Photoelectron Spectra Do Not Exhibit the Kondo Scale," Strongly Correlated Electron Materials Meeting, Los Alamos, New Mexico, January 19, 1994.

R. J. Bartlett and D. V. Morgan, "Measurement of the Ratio of Compton and Photoabsorption Single Ionization Cross Section for HE from 2 to 4 KeV," Atomic Physics Meeting, Boulder, Colorado, May 31, 1994.

D. A. Bauer, A. P. T. Palounek *et al.*, "Measurement of α_s in $e^+ e^-$ Annihilation at E(Cm) = 29 GeV," International Conference on High Energy Physics, Glasgow, Scotland, July 20-27, 1994.

R. L. Boudrie, "The Neutral Meson Spectrometer," Workshop on Large Experiments at Low Energy Hadron Facilities, Paul Scherrer Institute, Villigen, Switzerland, April 1994.

T. J. Bowles, "Neutrino Mass Measurements," International Conference on Fundamental Physics and Elementary Particles, Institute for Theoretical and Experimental Physics, Moscow, Russia, March 1994.

T. J. Bowles, "Review of Neutrino Mass Measurements," Particle and Nuclear Astrophysics and Cosmology in the Next Millennium Conference, Snowmass, Colorado, July 1994.

T. J. Bowles, "The Russian-American Gallium Experiment," Particle and Nuclear Astrophysics and Cosmology in the Next Millennium Conference, Snowmass, Colorado, July 1994.

T. J. Bowles, "The Russian-American Gallium Solar Neutrino Experiment," Neutrino Physics Symposium at American Chemical Society Annual Meeting, Washington, D.C., August, 1994.

A. Buyko, N. Bidylo, V. Chernysev, V. Demidov, S. Garanin, V. Kostyukov, A. Kulagin, A. Kuzyaev, A. Mezhevov, V. Mokhov, E. Pavlovskiy, A. Petrukhin, V. Yakubov, J. W. Canada, C. A. Ekdahl, J. H. Goforth, J. King, I. R. Lindemuth, R. E. Reinovsky, P. Rodriguez, R. C. Smith, L. R. Veeser, and S. M. Younger, "Results of the First Joint Russian-American High-Explosive Pulsed Power Experiment at Arzamas-16," IEEE International Conference on Plasma Science, Santa Fe, New Mexico, June 6-8, 1994.

S. E. Caldwell, "Colliding Plasmas," JOWOG-37, Sandia National Laboratories, Albuquerque, New Mexico, April 25-28, 1994.

M. W. Cappiello, P. W. Lisowski, and G. J. Russell, "Target/Blanket Design for the Los Alamos Accelerator Production of Tritium System," Accelerator-Driven Transmutation Technologies and Applications, Las Vegas, Nevada, July 1994.

A. Castro and E. B. Shera, "Electrophoresis of Single Fluorescent Molecule," Laser Applications to Chemical Analysis Topical Meeting (OSA), Jackson Hole, Wyoming, February 1994.

R. E. Chrien, “Time and Space-Resolved Triton Burnup Measurements on JT-6OU,” APS Division of Plasma Physics Meeting, Minneapolis, Minnesota, July 7, 1994.

M. D. Cooper, “Future Uses of the MEGA Apparatus,” Workshop on Large Experiments at Low-Energy Hadron Machines, Villigen, Switzerland, April 12, 1994.

D. S. Darrow and M. Tuszewski, “Measurement of Loss of DT Fusion Products Using Scintillator Detectors in TFTR,” 10th High-Temperature Plasma Diagnostics Conference, Rochester, New York, May 8-12, 1994.

P. R. Forman and L. D. Looney, “Fiber-Optic Large Area Average Temperature Sensor,” Optical Fiber Sensors Meeting, Glasgow, Scotland, April 15, 1994.

P. R. Forman and L. D. Looney, “Observed Phase Shift Due to Radiation Exposure in Optical Fibers,” SCK CEN (Belgian Nuclear Research Center), Mol, Belgium, April 28, 1994.

P. R. Forman, P. J. Rodriguez, and L. R. Veeser, “Optical Wheel-Rotation Sensor,” Optical Fiber Sensors Meeting, Glasgow, Scotland, April 15, 1994.

H. Frauenfelder, “From Symmetry to Complexity,” 1st International Symposium on Symmetries in Subatomic Physics, Taipei, Taiwan, May 1994.

J. S. George, “Spatial-Temporal Characterization of Visual Processing Combining MEG and Functional MRI,” Neuroscan, University of Chicago Symposium on Multimodal Registration, Chicago, Illinois, June 1994.

H. Hitzenberger, A. Pavlik, H. Vonach, M. B. Chadwick, R. C. Haight, R. O. Nelson, and P. G. Young, “Study of ^{27}Al (n,xγ) Reactions Up to a Neutron Energy of 400 MeV,” International Conference on Nuclear Data for Science and Technology, Gatlinburg, Tennessee, May 9-13, 1994.

M. Y. Hockaday, R. E. Chrien, B. R. Bartsch, J. C. Cochrane, J. S. Ladish, H. Oona, J. V. Parker, D. Platts, J. L. Stokes, L. R. Veeser, D. S. Sorenson, R. Walton, R. L. Bowers, H. Lee, A. J. Scannapieco, W. Anderson, W. Broste, R. Malone, and B. Warthen, “Liner Weapons Physics Experiments on Pegasus II,” JOWOG-37, Sandia National Laboratories, Albuquerque, New Mexico, April 25-28, 1994.

R. G. Hockaday, “Source to Detector Spectrum Transformation and Its Inverse for the Pegasus z-Pinch,” Dense z-Pinches Meeting, London, England, April 14, 1994.

R. P. Hoyt, J. T. Scheuer, K. F. Schoenberg, R. A. Gerwin, R. W. Moses, I. Henins, D. C. Black, and R. M. Mayo, “Optimization of a Coaxial Plasma Thruster with an Applied Magnetic Nozzle,” 30th Joint Propulsion Conference, Indianapolis, Indiana, June 1994.

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W. W. Hsing, T. A. Archuleta, D. A. Baker, J. Cobble, R. Chrien, N. Delamater, S. Eveans, J. Fernandez, R. Gibson, A. Hauer, T. Hurry, J. Jimerson, J. Mack, J. Oertel, T. Sedillo, and R. Watt, “ICF Experimental Research at Los Alamos National Laboratory,” China / United States / Japan Workshop on Laser Plasma and Drivers, Beijing, China, October 17-21, 1994.

W. W. Hsing, P. Aspen, C. A. Back *et al*., “Creation and Characterization of Long-Scale-Length Plasmas for Parametric Instability Studies,” JOWOG-37, Albuquerque, New Mexico, April 25-28, 1994.

W. W. Hsing, P. Aspen, B. H. Failor, N. Elliott, K. G. Estabrook, P. Gobe, D. H. Kalantar, B. J. MacGowan, D. S. Montgomery, T. D. Shepard, H. X. Vu, R. J. Wallace, and B. Wilde, “Long Scale Length Plasmas Created with Low Density Foams,” 24th Annual Anomalous Absorption Conference, Monterey, California, June 1994.

W. W. Hsing, R. Chrien, B. H. Failor, J. Fernandez, J. Colvin, N. Delamater, N. Elliott, P. Gobby, H. Kornblum, T. Murphy, M. Salazar, T. D. Shepard, G. F. Stone, and B. Wilde, “Creation and Characterization of a Long-Scale-Length Plasma in a Toroidal Gas-Filled Hohlraum,” 24th Annual Anomalous Absorption Conference, Monterey, California, June 1994.

R. J. Hughes, “Elementary Particles and the Equivalence Principle,” KFKI (Central Institute for Nuclear Physics), Budapest, Hungary, April 1994.

R. J. Hughes, “Antihydrogen,” Atomic Physics Seminar, Clarendon Laboratory, University of Oxford, England, May 1994.

R. J. Hughes, “Feynman’s Proof of Maxwell’s Equations,” Seminar at Physics Department, University of Oxford, England, May 1994.

R. J. Hughes, “Quantum Cryptography,” Department of Physics Colloquium, University of Liverpool, England, May 1994; Evening Lecture at Christ Church, Oxford, England, May 1994; Seminars at Rutherford and Appleton Laboratory, Chilton, England, Imperial College, London, England, Physics Department, Oxford University, England, and Physics Department, University of Southampton, England, June 1994; Center for Advanced Studies, Physics Department, University of New Mexico, Albuquerque, New Mexico, July 1994; and Physics and Astronomy Colloquium, University of New Mexico, Albuquerque, New Mexico, December 9, 1994.

R. J. Hughes, “Experimental Quantum Cryptography,” Workshop on Quantum Computing and Communication, NIST, Gaithersburg, Maryland, August 1994.

R. J. Hughes, “The Los Alamos Quantum Cryptography Project,” National Security Agency Meeting, Fort Meade, Maryland, October 1994.

B. V. Jacak, “Two Particle Correlations from the CERN Experiments at Midrapidity,” CORINNE II - International Workshop on Multi-Particle Correlations and Nuclear Reactions, Nantes, France, September 1994.

B. V. Jacak, “Review of Heavy Ion Physics,” 27th International Conference on High-Energy Physics, Glasgow, Scotland, July 1994.

B. V. Jacak, “Single and Two Particle Distributions from *p*-A and A-A Collisions,” 10th Winter Workshop on Nuclear Dynamics, Snowbird, Utah, January 1994.

D. M. Jansen, “Production of Beauty and Charm from Fermilab Experiment 789,” APS Meeting, Physics of Beams, Washington, D.C., April 1994.

D. L. Jassby *et al.*, “Absolute Calibration by a Neutron Generator of TFTR Neutron Detectors for D-T Plasma Operation,” 10th Topical Conference on High-Temperature Plasma Diagnostics, Rochester, New York, May 1994.

L. C. Johnson *et al.*, “Cross Calibration of Neutron Detectors for Deuterium-Tritium Operation in TFTR, “ 10th Topical Conference on High-Temperature Plasma Diagnostics, Rochester, New York, May 1994.

L. C. Johnson, C. W. Barnes *et al.*, “Tritium Transport Studies on TFTR,” Proceedings of 21st EPS Conference on Controlled Fusion and Plasma Physics, Montpellier, France, June 27, 1994.

J. S. Kapustinsky, E. Perrin *et al.* (SMD Collaboration), “Heat Transfer Using Aluminum Nitride in a Silicon Microvertex Detector,” WELDEC, 1st International Workshop on Electronics and Detector Cooling, Lausanne, Switzerland, October 4-7, 1994.

R. E. Kelly, “EMP from a Chemical Explosion Originating in a Tunnel,” Nonproliferation Experiments, Results, and Implications Meeting, Livermore, California, February 17, 1994, and Nonproliferation Experiment (NPE) Meeting, Washington, D.C., March 22, 1994.

N. S. P. King, K. L. Albright, S. A. Jaramillo, T. E. McDonald, G. J. Yates, and B. T. Turko, “High-Frame Rate CCD Cameras with Fast-Optical Shutters for Military and Medical Imaging Applications,” SPIE International Symposium on Optics, Imaging, and Instrumentation, San Diego, California, July 24-29, 1994.

M. Kroupa, “Performance of the Photon Pair Spectrometers for the MEGA Experiment,” APS Spring Meeting, Washington, D.C., April 18-22, 1994.

G. A. Kyrala, J. Abdallah, D. P. Kilcrease, R. D. Fulton, G. L. Olson, A. Ya. Faenov, I. Yu Skobelev, and S. A. Pikuz, “High Resolution Spectroscopy of Silicon Plasma at Ultrahigh Irradiance,” International Conference on Lasers ’94, Quebec, Canada, December 1994.

I. R. Lindemuth, R. Kirkpatrick, R. E. Reinovsky, P. T. Sheehey, R. S. Thurston, B. G. Anderson, J. W. Canada, R. E. Chrien, C. A. Ekdahl, C. Findley, J. H. Goforth, H. Oona, P. Rodriguez, J. S. Shlachter, R. C. Smith, G. L. Stradling, V. K. Chernyshev, V. N. Dolin, S. F. Garanin, V. P. Korchagin, V. N. Mohkov, I. V. Morozov, S. V. Pak, E. S. Pavlovskii, and G. I. Volkov, "Plasma Formation Experiments Relevant to Magnetized Target Fusion," IEEE International Conference on Plasma Science, Santa Fe, New Mexico, June 6-8, 1994.

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P. W. Lisowski, "Nuclear Science Research at the WNR and LANSCE Neutron Sources," International Conference on Nuclear Data for Science and Technology, Gatlinburg, Tennessee, May 9-13, 1994.

J. M. Mack, A. Hauer, R. E. Chrien *et al*., "Los Alamos Contributions to Target Diagnostics on the National Ignition Facility," American Nuclear Society Topical Conference on Fusion Technology, New Orleans, Louisiana, June 1994.

A. Michaudon, "Basic Physics with Spallation-Neutron Sources," American Nuclear Society, La Grange Park, Illinois, 1994.

R. O. Nelson and S. A. Wender, "Neutron-Induced Gamma-Ray Production from Carbon and Nitrogen," International Conference on Nuclear Data for Science and Technology, Gatlinburg, Tennessee, May 9-13, 1994.

A. Pavlik, H. Vonach, M. B. Chadwick, R. C. Haight, R. O. Nelson, S. A. Wender, and P. G. Young, "^{207,208}Pb (n,xnγ) Reactions for Neutron Energies up to 200 MeV," International Conference on Nuclear Data for Science and Technology, Gatlinburg, Tennessee, May 9-13, 1994.

S. I. Penttila, "Study of Parity Violation in Compound Nucleus Using Polarized Epithermal Neutrons," APS Spring Meeting, Washington, D.C., April 1994.

J. A. Phillips, D. A. Baker, and R. F. Gribble, "Shells, Gaps, Fluctuations, and Loop-Voltages in the Reversed-Field Pinch Experiment ZT-4OM," APS Division of Plasma Physics, 36th Annual Meeting, Minneapolis, Minnesota, November 7-11, 1994.

D. J. Rej, "Cost Estimates for Commercial PSII," IEEE International Conference on Plasma Science, Santa Fe, New Mexico, June 1994.

D. J. Rej, "Beams 94," 10th International Conference on High-Current Particle Beams, San Diego, California, June 1994.

R. G. H. Robertson, T. J. Bowles, P. J. Doe, M. M. Fowler, J. V. Germani, A. Hime, G. G. Miller, R. W. Ollerhead, P. M. Thornewell, J. B. Wilhelmy, J. M. Wouters, and J. F. Wilkerson, "Low-Background Techniques in Development of Neutral Current Detectors for the Sudbury Neutrino Observatory (SNO) Detector," APS Meeting, Crystal City, Virginia, April 12-15, 1994.

R. G. H. Robertson *et al.*, "Low-Background Counting Facility for the Development of Neutral Current Detectors to be Deployed in the Sudbury Neutrino Observatory (SNO) Detector," APS Meeting, Washington, D.C., April 1994.

R. G. H. Robertson *et al.*, "Low-Background Techniques in the Development of Neutral Current Detectors for the Sudbury Neutrino Observatory (SNO) Detector," APS Meeting, Washington, D.C., April 1994.

W. C. Sailor, C. W. Barnes, R. E. Chrien, and G. A. Wurden, "Conceptual Design for a Scintillating-Fiber Neutron Detector for Fusion Reactor Plasma Diagnostics," 10th Topical Conference on High-Temperature Plasma Diagnostics, Rochester, New York, May 8-12, 1994.

W. C. Sailor, C. W. Barnes, R. E. Chrien, and G. A. Wurden, "Conceptual Design for a Fast Neutron Ionization Chamber for Fusion Reactor Plasma Diagnostics," 11th Topical Meeting on the Technology of Fusion Energy, American Nuclear Society, New Orleans, Louisiana, June 19-23, 1994.

J. T. Scheuer, R. P. Hoyt, K. F. Schoenberg, R. A. Gerwin, R. W. Moses, I. Henins, R. M. Mayo, and D. C. Black, "Reduction of the Anode Fall in a Coaxial Plasma Thruster with an Applied Magnetic Nozzle," 11th Symposium on Space Nuclear Power and Propulsion, Albuquerque, New Mexico, January 1994.

J. T. Scheuer, R. P. Hoyt, K. F. Schoenberg, R. A. Gerwin, R. W. Moses, and I. Henins, "Application of MPD Thruster Technology to Advanced and Environmentally Conscious Manufacturing," 30th Joint Propulsion Conference, Indianapolis, Indiana, June 1994.

S. J. Seestrom, "Recent Results in Parity Violation from LANSCE," 2nd International Seminar on Interaction of Neutrons with Nuclei: Neutron Spectroscopy, Nuclear Structure, and Related Topics, Dubna, Russia, April 26-28, 1994.

J. S. Shlachter, "Fiber z-Pinch Instabilities," 3rd International Conference on Dense z-Pinches, Imperial College, London, April 1994.

J. E. Simon-Gillo, "Deuteron Production in Heavy Ion Collisions at CERN Energies," Budapest Workshop on High-Energy Heavy Ion Physics, Budapest, August 25, 1994.

J. E. Simon-Gillo, "Single Particle Measurements and Two Particle Interferometry Results from CERN Experiment NA44," Division of Particles and Fields '94, Albuquerque, New Mexico, August 1994.

J. Strachan *et al*., "Absolute Calibration of TFTR Helium Proportional Counters," 10th Topical Conference on High-Temperature Plasma Diagnostics, Rochester, New York, May 8-10, 1994.

G. L. Stradling, R. M. Baltrusiatis, and C. S. Young, "Energy Selective Reaction History," NEDPC, Livermore, California, September 30, 1994.

P. Staples and P. W. Lisowski, "Use of the WNR Spallation Neutron Source at LAMPF to Determine the Absolute Efficiency of a Neutron Scintillation Detector," International Conference on Nuclear Data for Science and Technology, Gatlinburg, Tennessee, May 9-13, 1994.

J. K. Studebaker and R. D. Fulton, "Nonlinear Response of the Photo Cathode of an X-ray Streak Camera to UV Light," Ultrahigh and High-Speed Photography and Videography Meeting, San Diego, California, January 11, 1994.

J. P. Sullivan, "Second Generation Interferometry Experiments at CERN," 5th Conference on the Intersections of Particle and Nuclear Physics, St. Petersburg, Florida, June 1994.

J. P. Sullivan, "Pion and Kaon Freezeout in NA44," NATO Advanced Research Workshop on Hot Hadronic Matter: Theory and Experiment, Divonne les Bains, France, June 1994.

T. N. Taddeucci, "Quasi-Free (p,n) Spin Responses," University of Colorado, Nuclear Physics Laboratory Seminar, Boulder, Colorado, July 27, 1994.

T. N. Taddeucci, "Nuclear Isovector Spin Responses from $(\vec{p}, \vec{n})$ Reactions at 494 MeV," International Symposium on Spin-Isospin Responses and Weak Processes in Hadrons and Nuclei, Osaka, Japan, March 8-10, 1994.

T. N. Taddeucci, "Calibration and Operation of the NTOF Polarimeter at LAMPF," Workshop on Recent Development of Proton, Neutron, and Deuteron Polarimeters for Spin Physics at Intermediate Energies, RCNP, Osaka University, Osaka, Japan, March 11-12, 1994.

T. N. Taddeucci, "The Nuclear Spin-Isospin Response to Quasi-Free Nucleon Scattering," 8th International Symposium on Polarization Phenomena in Nuclear Physics, Bloomington, Indiana, September 15-22, 1994.

M. W. Tilden, "Explorations in the Robot Jurassic Park," Alife Robotics Colloquium, Santa Fe Institute, Santa Fe, New Mexico, March 17, 1994; Design Engineers Conference, Toronto, Canada, May 6-7, 1994; Sandia Robotics Colloquium, Albuquerque, New Mexico, April 15, 1994; United States Air Force Scientific Advisory Board Meeting, Los Alamos, New Mexico, March 15, 1994; and 3rd BEAM Robot Olympic Games, Ontario, Canada, March 6-8, 1994.

J. A. Tobin, M. Tuszewski, I. H. Campbell, and J. T. Scheuer, "A Novel Technique for Semiconductor Thin Film Growth," IEEE International Conference on Plasma Science, Santa Fe, New Mexico, June 1994.

M. Tuszewski, “Efficiency of Inductively Coupled Plasmas for Environmental Recycling,” Plasma Technology Incorporated Workshop, Santa Fe, New Mexico, February 23, 1994.

M. Tuszewski *et al*., “Downstream Comparison of Four Inductive Plasma Sources,” 21st IEEE International Conference on Plasma Science, Santa Fe, New Mexico, June 6-8, 1994.

J. L. Ullmann, P. A. Staples, G. Butler, M. M. Fowler, A. Gavron, R. Gritzo, D. Jagnow, J. D. King, R. Laird, P. W. Lisowski, D. Mayo, R. O. Nelson, L. Waters, S. A. Wender, J. Wilhelmy, W. Wilson, M. A. Yates, and C. Zoeller, “Thick Target Spallation Product Yields from 800-MeV Protons on Tungsten,” International Conference on Nuclear Data for Science and Technology, Gatlinburg, Tennessee, May 9-13, 1994.

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